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(54) Title: RADIOACTIVE-EMISSION-MEASUREMENT OPTIMIZATION TO SPECIFIC BODY STRUCTURES

(57) Abstract: Systems, methods, and probes are provided for functional imaging by radioactive-emission-measurements, specific to body structures, such as the prostate, the esophagus, the cervix, the uterus, the ovaries, the heart, the breast, the brain, and the whole body, and other body structures. The nuclear imaging may be performed alone, or together with structural imaging, for example, by x-rays, ultrasound, or MRI. Preferably, the radioactive-emission-measuring probes include detectors, which are adapted for individual motions with respect to the probe housings, to generate views from different orientations and to change their view orientations. These motions are optimized with respect to functional information gained about the body structure, by identifying preferred sets of views for measurements, based on models of the body structures and information theoretic measures. A second iteration, for identifying preferred sets of views for measurements of a portion of a body structure, based on models of a location of a pathology that has been identified, makes it possible, in effect, to zoom in on a suspected pathology. The systems are preprogrammed to provide these motions automatically.

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RADIOACTIVE-EMISSION-MEASUREMENT OPTIMIZATION TO SPECIFIC BODY STRUCTURES

FIELD AND BACKGROUND OF THE INVENTION

The present invention relates to nuclear imaging and more particularly, to systems, methods, and probes for radioactive-emission-measurement optimization to specific body structures, possibly together with structural imaging, for example, by x-rays, ultrasound, or MRI.

Radioactive-emission imaging relies on the fact that in general, pathologies, such as malignant tumors, malfunctioning organs, and inflammations, display a level of activity different from that of healthy tissue. Thus, radiopharmaceutical, which circulate in the blood stream, are picked up by the active pathologies to a different extent than by the surrounding healthy tissue; in consequence, the pathologies are operative as radioactive-emission sources and may be detected by radioactive-emission imaging.

The pathological feature may appear as a concentrated source of high radiation, or a hot region, as may be associated with a tumor, or as a region of low-level radiation, which is nonetheless above the background level, as may be associated with carcinoma. Additionally, a reversed situation is possible. Dead tissue has practically no pick up of radiopharmaceuticals, and is thus operative as a region of little radiation, or a cold region, below the background level.

Thus radiopharmaceuticals may be used for identifying active pathologies as well as dead tissue, and the image that is constructed is generally termed, a functional image.

The mechanism of localization of a radiopharmaceutical in a particular organ of interest depends on various processes in the organ of interest, such as antigen-antibody reactions, physical trapping of particles, receptor site binding, removal of intentionally damaged cells from circulation, and transport of a chemical species across a cell membrane and into the cell by a normally operative metabolic process. A summary of the mechanisms of localization by radiopharmaceuticals is described in http://www.lunis.luc.edu/nucmed/tutorial/radpharm/i.htm. For example:

1. Active transport involves the use of a normally operative metabolic pathway in the body, for moving a radiopharmaceutical across a cell membrane and

into the cell. An example of a radiopharmaceutical that may be used for active transport is I^{131} in the form of NaI, for thyroid imaging.

2. Phagocytosis involves physical entrapment of colloidal particles by Kupffer cells in the RE System. An example of a radiopharmaceutical that may be used for phagocytosis is Tc^{99m} in the form of sulfur colloid, for liver and spleen imaging.

3. Capillary blockage involves intentional microembolization of a capillary bed with particles. An example of a radiopharmaceutical that may be used for capillary blockage is Tc^{99m} in the form of MAA, for pulmonary perfusion imaging.

4. Cell sequestration involves injection of damaged RBC's to produce a spleen scan with no visualization of the liver. An example of a radiopharmaceutical that may be used for cell sequestration is heat damaged autologous Tc^{99m} RBC's.

5. Simple or exchange diffusion involves a mechanism whereby a radiotracer diffuses across cell membranes and then binds or attaches itself to a cell component. An example of a radiopharmaceutical that may be used for simple or exchange diffusion is F^{18}, in the form of NaF, for bone imaging.

6. Compartmental Localization involves placement of a radiotracer in a fluid space and imaging of that fluid space. Examples of radiopharmaceuticals that may be used for compartmental localization are Tc^{99m} HAS, for MUGA's, In^{111} DTPA, for cisternograms, and Xe^{133} gas for pulmonary perfusion.

7. Chemisorption involves surface binding of radiopharmaceutical to a solid structure. An example of a radiopharmaceutical that may be used for chemisorption is In^{111} platelets bound to a surface of an active thrombus.

8. Antigen or antibody reaction involves uptake at tumor site due to specific binding of radiolabeled antibody to surface antigens on tumors. Examples of radiopharmaceuticals that may be used for antigen or antibody reaction are In^{111} Oncoscint, for the localization of recurrent ovarian or colorectal carcinoma, or In^{111} ProstaScint for the localization or recurrent cancer.

9. Receptor binding involves the binding of a radiopharmaceutical to high-affinity receptor sites. An example of a radiopharmaceutical that may be used for receptor binding is In^{111} octreotide, for localization of neuroendocrine and other tumors based on binding of a somatostatin analog to receptor sites in tumors.

Examples of other radiopharmaceuticals include the following:

1. anti-CEA, a monoclonal antibody fragment, which targets CEA – produced and shed by colorectal carcinoma cells – and may be labeled by Tc^{99m} or by other radioisotopes, for example, iodine isotopes (Jessup JM, 1998, Tumor markers – prognostic and therapeutic implications for colorectal carcinoma, Surgical Oncology; 7: 139-151);

2. In^{111}-Satumomab Pendetide (Oncoscint®), designed to target TAG-72, a mucin-like glycoprotein, expressed in human colorectal, gastric, ovarian, breast and lung cancers, but rarely in healthy human adult tissues (Molinolo A; Simpson JF; et al., 1990, Enhanced tumor binding using immunohistochemical analyses by second generation anti-tumor-associated glycoprotein 72 monoclonal antibodies versus monoclonal antibody B72.3 in human tissue, Cancer Res., 50(4): 1291-8);

3. Lipid-Associated Sialic Acid (LASA), a tumor antigen, used for colorectal carcinoma, with a similar sensitivity as anti-CEA monoclonal antibody fragment but a greater specificity for differentiating between benign and malignant lesions (Ebril KM, Jones JD, Klee GG, 1985, Use and limitations of serum total and lipid-bound sialic acid concentrations as markers for colorectal cancer, Cancer; 55:404-409);

4. Matrix Metaloproteinase-7 (MMP-7), a proteins enzyme, believed to be involved in tumor invasion and metastasis (Mori M, Barnard GF et al., 1995, Overexpression of matrix metalloproteinase-7 mRNA in human colon carcinoma, Cancer; 75: 1516-1519);

5. Ga^{67} citrate, used for detection of chronic inflammation (Mettler FA, and Guiberteau MJ, Eds., 1998, Inflammation and infection imaging, Essentials of nuclear medicine, Fourth edition, Pgs: 387-403);

6. Nonspecific-polyclonal immunoglobulin G (IgG), which may be labeled with both In^{111} or Tc^{99m}, and which has a potential to localize nonbacterial infections (Mettler FA, and Guiberteau MJ, ibid);

7. Radio-labeled leukocytes, such as such as In^{111} oxine leukocytes and Tc^{99m} HMPAO leukocytes, which are attracted to sites of inflammation, where they are activated by local chemotactic factors and pass through the endothelium into the soft tissue (Mettler FA, and Guiberteau MJ, ibid; Corstens FH; van der Meer JW,

1999, Nuclear medicine's role in infection and inflammation, Lancet; 354 (9180): 765-70); and

8. Tc^{99m} bound to Sodium Pertechnetate, which is picked up by red blood cells, and may be used for identifying blood vessels and vital organs, such as the liver and the kidneys, in order to guide a surgical instrument without their penetration.

The particular choice of a radionuclide for labeling antibodies depends upon the chemistry of the labeling procedure and the isotope nuclear properties, such as, the number of gamma rays emitted, their respective energies, the emission of other particles, such as beta or positrons, the isotope half-life, and the existence of different isotopes of identical chemistry but different half-lives (e.g., I^{131} and I^{133}). The usual preferred emission for medical applications is that of gamma rays, with an energy range of approximately 11- 511 KeV. However, beta and positron radiation may also be detected.

The detector may be a room temperature, solid-state CdZnTe (CZT) detector, configured as a single-pixel or a multi-pixel detector, obtained, for example, from eV Products, a division of II-VI Corporation, Saxonburg Pa., 16056, or from IMARAD IMAGING SYSTEMS LTD., of Rehovot, ISRAEL, 76124, www.imarad.com, or from another source. Alternatively, another solid-state detector such as CdTe, HgI, Si, Ge, or the like, or a scintillation detector (such as NaI(Tl), LSO, GSO, CsI, CaF, or the like, or a combination of a scintillation detector and a photomultiplier, to form an Anger camera, or another detector as known, may be used.

Figures 1A and 1B schematically illustrate a detecting unit 12 and a block 90 of detecting units 12, respectively, as known.

As seen in Figure 1A, the detecting unit 12 is formed of a single-pixel detector 91, having a diameter D and a thickness τ_d. Both the detector diameter D, or a diameter equivalent, in the case of a non-circular detector, and the detector thickness τ_d affect the detecting efficiency. The detector diameter D determines the surface area on which radioactive emission impinges; the greater the surface area, the greater the efficiency. The detector thickness τ_d affects the stopping power of the detector. High energy gamma rays may go through a thin detector; the probability of their detection increases with the detector thickness τ_d.

Figure 1A illustrates a single-pixel detector 91, which by itself cannot generate an image; rather, all counts are distributed over the surface area of the detector 91.

As seen in Figure 1B, the block 90 includes a plurality of the detecting unit 12, formed by dividing the detector 91 into a plurality of electrically insulated pixels 106, each associated with a collimator 96. The collimators 96 are of the diameter or diameter equivalent D, a length L, and a septa thickness τ. The collimators 96 may be, for example, of lead, tungsten or another material which substantially blocks gamma and beta rays. The collimators 96 may be shaped as tubes, rectangular grids, or grids of another polygon. Wide-angle or narrow-angle collimators are also possible.

The collimator's geometry, and specifically, the ratio of D/L, provides the detecting unit 12 with a collection solid angle δ analogous to a viewing solid angle of an optical camera. The collection solid angle δ limits the radioactive-emission detection to substantially only that radioactive emission, which impinges on the detector 91 after passing through a "corridor" of the collimator 96 (although in practice, some high-energy gamma rays may penetrate the collimator's walls). With no collimator, the collection angle δ, is essentially a solid angle of 4π steradians.

Thus, the collimator's geometry affects both the detection efficiency and the image resolution, which are defined as follows:

i. The detection efficiency is the ratio of measured radiation to emitted radiation; and

ii. The image resolution is the capability of making distinguishable closely adjacent manifestations of a pathology, or the capability to accurately determine the size and shape of individual manifestations of a pathology.

Naturally, it is desired to optimize both the detection efficiency and the image resolution. Yet, they are inversely related to each other. The detection efficiency increases with increasing collimator's collection angle, and the image resolution decreases with increasing collimator's collection angle.

In other words, while a wide-aperture, single-pixel detecting unit, such as that of Figure 1A provides high efficiency, it does not lend itself to the generation of a two-dimensional image, and the wide aperture blurs the information regarding the

direction from which the radiation comes. Yet as the resolution is increased, for example, to the detecting unit 12 of Figure 1B, the detection efficiency is decreased.

Commonly owned US Applications 20040015075 and 20040054248 and commonly owned PCT publication WO2004/042546, all of whose disclosures are incorporated herein by reference, describe systems and methods for scanning a radioactive-emission source with a radioactive-emission-measuring probe of a wide-aperture collimator, and at the same time, monitoring the position of the radioactive-emission-measuring probe, at very fine time intervals, to obtain the equivalence of fine-aperture collimation. In consequence, high-efficiency, high-resolution images of a radioactivity emitting source are obtained.

A system according to US Applications 20040015075 and 20040054248 and PCT publication WO2004/042546 is seen in Figures 2 – 3B.

Figure 2 schematically illustrates the basic component of a system 120, comprising a radioactive-emission-measuring probe 122 and a position-tracking device 124, both in communication with a data processing unit 126. The radioactive-emission-measuring probe 122 is associated with a first coordinate system 128, and the position-tracking device 124 is associated with a second coordinate system 128', wherein the position-tracking device 124 monitors the position of the radioactive-emission-measuring probe 122 as a function of time. The data processing unit 126 processes the measurements of both the radioactive-emission-measuring probe 122 and the position-tracking device 124 and combines them, to form the image.

Figure 3A schematically illustrates the manner of operating the radioactive-emission-measuring probe 122 with the position-tracking device 124 of the system 120. The radioactive-emission-measuring probe 122 moves about an area of radioactive emission 110, for example, in the direction of an arrow 118, so as to measure a radioactive emission distribution 112, as a function of time, while the position-tracking device 124 monitors the position of probe 122. The radioactive-emission-measuring probe 122 may be a single-pixel detector of high efficiency, which is incapable, by itself, of producing images. Nonetheless, a data processing unit 126, processes a radioactive-count-rate input 121 together with a position-tracking input 123, using algorithms 125, to reconstruct an image 110' of the area of radioactive emission 110, for example, on a display unit 129.

Images according to this concept are illustrated in Figures 3B – 3B. The area of radioactive emission 110 is located in a two-dimensional coordinates u;v, and includes two hot points 115 (Figure 3B). The system 120 moves from a position P(1) at a time t(1), to a position P(2) at a time t(2), while measuring the radioactive emission distribution 112 of the area of radioactive emission 110, including the hot points 115.

An example of a suitable position-tracking device 124 is miniBird™, which is a magnetic tracking and location system commercially available from Ascension Technology Corporation, P.O. Box 527, Burlington, Vermont 05402 USA (http://www.ascension-tech.com/graphic.htm). The miniBird™ measures the real-time position and orientation (in six degrees of freedom) of one or more miniaturized sensors, so as to accurately track the spatial location of probes, instruments, and other devices. The dimensions of miniBird™ 124 are 18 mm x 8 mm x 8 mm for the Model 800 and 10 mm x 5 mm x 5 mm the Model 500. Alternatively, an optical tracking device, of Northern Digital Inc., Ontario, Canada NDI-POLARIS, which provides passive or active systems, a magnetic tracking device of NDI-AURORA, an infrared tracking device of E-PEN system, http://www.e-pen.com, or an ultrasonic tracking device of E-PEN system may be used. Additionally or alternatively, the position-tracking device may be an articulated-arm position-tracking device, an accelerometer-based position-tracking device, a potentiometer-based position-tracking device, or a radio-frequency-based position-tracking device.

Commonly owned US application 20040054248 and commonly owned PCT publication WO2004/042546 further disclose various extracorporeal and intracorporeal systems 120, of radioactive-emission-measuring probes 122, of relatively wide apertures, associated with position-tracking devices 124. Examples of extracorporeal and intracorporeal radioactive-emission-measuring probes of this type, operative with position-tracking devices, are seen in Figures 4A – 4C.

Figure 4A schematically illustrates a hand-held, extracorporeal probe 170, formed as the system 120, and having the radioactive-emission-measuring probe 122 of a detector 132, a collimator 134 and a controller 130, and further including the position-tracking device 124, wherein the radioactive-emission-measuring probe 122 and the position-tracking device 124 are associated with the data processing unit 126, as taught in conjunction with Figures 2 – 3B.

Figure 4B schematically illustrates an intracorporeal probe 180, formed as the system 120, mounted on a catheter 136, and having the radioactive-emission-measuring probe 122, of the detector 132 and the collimator 134, and the position-tracking device 124, wherein the probe 122 and the position tracking device 124 are associated with the data processing unit 126, as taught in conjunction with Figures 2 – 3B. The intracorporeal probe 180 is configured to penetrate a tissue 135, via a trucar valve 138. A structural imager, such as an ultrasound imager 137 or an MRI probe 137 may further be included.

Figure 4C schematically illustrates an intracorporeal probe 190, formed as the system 120, adapted for rectal insertion and having the radioactive-emission-measuring probe 122, formed as a plurality of detectors 132 and collimators 134, and associated with the position-tracking device 124. The intracorporeal probe 190 may be further adapted for motion along the x and ω directions. For example, the intracorporeal probe 190 may include a motor 154 for self-motion in the x and ω directions, so as to crawl into the rectum. The motor 154 may be obtained, for example, from B-K Medical A/S, of Gentofte, DK, and may be adapted to report to the data processing unit 126 the exact position and orientation of the intracorporeal probe 190, based on the number of rotations. In some embodiments, the motor 154 is used in place of the position-tracking device 124. Alternatively, it is used in addition to it. The intracorporeal probe 190 may further include the structural imager 137, such as an ultrasound imager or an MRI probe.

The acquisition of both a functional image of the body, such as a radioactive-emission image, and a structural image, such as an ultrasound, an x-ray, or an MRI image, and their co-registration on a single frame of reference, is disclosed by commonly owned US Patent 6,173,201 to Front, whose disclosure is incorporated herein by reference, as well as by M. W. Vannier and D. E. Gayou, "Automated registration of multimodality images", Radiology, vol. 169 pp. 860-861 (1988); J. A. Correia, "Registration of nuclear medicine images, J. Nucl. Med., vol. 31 pp. 1227-1229 (1990); J-C Liehn, A. Loboguerrero, C. Perault and L. Demange, "superposition of computed tomography and single photon emission tomography immunoscinigraphic images in the pelvis: validation in patients with colorectal or ovarian carcinoma recurrence", Eur. J. Nucl. Med., vol. 19 pp. 186-194 (1992); F. Thomas et al., "Description of a prototype emission transmission computed

tomography imaging system", J. Nucl. Med., vol. 33 pp. 1881-1887 (1992); D. A. Weber and M. Ivanovic, "Correlative image registration", Sem. Nucl. Med., vol. 24 pp. 311-323 (1994); and Hasegawa et al., U.S. Pat. No. 5,376,795.

In essence, several images may be acquired and co-registered to the same frame of reference, as follows:

i. a first functional image scan, based for example, on anti-CEA monoclonal antibody fragment, labeled by iodine isotopes, may be acquired for targeting CEA - produced and shed by colorectal carcinoma cells for detecting a pathological feature, such as colorectal carcinoma;

ii. a second functional image, based for example, on nonspecific-polyclonal immunoglobulin G (IgG), which may be labeled with Tc^{99m}, may be acquired for locating blood vessels and vital structures, such as the heart, or the stomach, co-registered with the first functional image and the pathological feature detected on it, in order to locate the pathological feature in reference to blood vessels and vital organs; and

iii. a structural image, such as an ultrasound image, may be used for general structural anatomy, co-registered with the first and second functional images, in order to locate the pathological feature in reference to bones and the general anatomic structure.

In this manner, a physician may locate the pathological feature in reference to the blood vessels, vital organs, and the bones.

Additionally, correlation may be used to guide a minimally invasive surgical instrument to the pathological feature, while avoiding the blood vessels, vital organs, and bones. The minimally invasive surgical instrument may be a biopsy needle, a wire, for hot resection, a knife for cold resection, an instrument of focused energy, to produce ablation, for example, by ultrasound, or by laser, an instrument for cryosurgery, an instrument for croyetherapy, or an instrument for bractherapy, wherein seeds of a radioactive metal are planted close to a tumor, for operating as a radioactive source near the tumor.

Commonly owned PCT publication WO2004/042546 further discloses that the surgical instrument may be visible on at least one of the images, for example, on the structural image, to enable the physician to see the instrument, the pathological feature, and the surrounding anatomy on the display 129 (Figure 3A). Additionally,

the surgical instrument may be radioactively labeled, to be visible also on the functional image.

Commonly owned US Patent 6,173,201 discloses a method of stereotactic therapy, wherein a frame, which includes at least three markers, visible on a structural image, is rigidly secured to a patient. The structural image of a region inside the patient's body, which includes a pathological feature and the markers, is acquired. A functional image of the pathological feature is then acquired and co-registered with the structural image, to correlate the images to the same frame of reference. A stereotactic guide is rigidly attached to the frame and is used to guide a surgical instrument, such as a biopsy needle or a brachytherapy needle, to the pathological feature, with reference to the co-registered images.

Commonly owned PCT publication WO2004/042546 further disclosures the use of a structural image, such as of ultrasound or MRI, for information about tissue attenuation. The information may then be used to correct the radioactive-emission measurements.

Nuclear imaging for coronary artery disease is also known. For example, US Patent 6,597,940, to Bishop, et al, relates to screening patients for an early stage of coronary artery disease. According to this method, a patient is screened based on the time-activity curve for a radioactive tracer passing through a left ventricle region of the patient's body. According to another aspect of the invention, an array of gamma particle detectors is employed to obtain data for a region of interest that is larger than and encompasses a left ventricle region of the patient's body. An analysis of the data identifies the subset of the region of interest that corresponds to the left ventricle region. According to a further aspect of the present invention, a second technique is employed to locate the left ventricle region. A still further aspect of the present invention relates to obtaining images of a patient's heart using a high temporal resolution gamma camera.

Additionally, US Patent 6,671,541, to Bishop et al. relates to a cardiovascular imaging and functional analysis system and method, wherein a dedicated fast, sensitive, compact and economical imaging gamma camera system that is especially suited for heart imaging and functional analysis is employed. The cardiovascular imaging and functional analysis system of the present invention can be used as a dedicated nuclear cardiology small field of view imaging camera. The disclosed

cardiovascular imaging system and method has the advantages of being able to image physiology, while offering an inexpensive and portable hardware, unlike MRI, CT, and echocardiography systems. The cardiovascular imaging system of the invention employs a basic modular design suitable for cardiac imaging with one of several radionucleide tracers. The detector can be positioned in close proximity to the chest and heart from several different projections, making it possible rapidly to accumulate data for first-pass analysis, positron imaging, quantitative stress perfusion, and multi-gated equilibrium pooled blood (MUGA) tests.. In a preferred embodiment, the Cardiovascular Non-Invasive Screening Probe system can perform a novel diagnostic screening test for potential victims of coronary artery disease. The system provides a rapid, inexpensive preliminary indication of coronary occlusive disease by measuring the activity of emitted particles from an injected bolus of radioactive tracer. Ratios of this activity with the time progression of the injected bolus of radioactive tracer are used to perform diagnosis of the coronary patency (artery disease).

SUMMARY OF THE INVENTION

The present invention successfully addresses the shortcomings of the presently known configurations by providing systems, methods, and probes for functional imaging by radioactive-emission-measurements, specific to body structures, such as the prostate, the esophagus, the cervix, the uterus, the ovaries, the heart, the breast, the brain, and the whole body, and other body structures. The nuclear imaging may be performed alone, or together with structural imaging, for example, by x-rays, ultrasound, or MRI. Preferably, the radioactive-emission-measuring probes include detectors, which are adapted for individual motions with respect to the probe housings, to generate views from different orientations and to change their view orientations. These motions are optimized with respect to functional information gained about the body structure, by identifying preferred sets of views for measurements, based on models of the body structures and information theoretic measures. A second iteration, for identifying preferred sets of views for measurements of a portion of a body structure, based on models of a location of a pathology that has been identified, makes it possible, in effect, to zoom in on a suspected pathology. The systems are preprogrammed to provide these motions automatically.

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present invention, suitable methods and materials are described below. In case of conflict, the patent specification, including definitions, will control. In addition, the materials, methods, and examples are illustrative only and not intended to be limiting.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is herein described, by way of example only, with reference to the accompanying drawings. With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention only, and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

In the drawings:

FIGs. 1A – 1B schematically illustrate detecting units and blocks for radioactive emission detection as known;

FIG. 2 schematically illustrates the basic component of a system, comprising a radioactive-emission-measuring probe and a position-tracking device, both in communication with a data processing unit;

FIGs. 3A – 3B schematically illustrate the manner of operating the radioactive-emission-measuring probe with the position-tracking device;

FIGs. 4A – 4C schematically illustrate extracorporeal and intracorporeal radioactive-emission-measuring probes operative with position-tracking devices;

FIGs. 5A – 5F present the principles of modeling, for obtaining an optimal set of views, in accordance with the present invention;

FIGs. 6A and 6B pictorially illustrate a view and viewing parameters associated with it, in accordance with definitions of the present invention;

FIGs. 7A – 7C schematically illustrate anatomical constraints, which are to be modeled, in accordance with the present invention;

FIG. 8 illustrates, in flowchart form, a method of predefining a set of views for functional imaging, tailored for imaging from esophagus, and optimized with respect to the functional information gained about the body structure, in accordance with the present invention;

FIGs. 9A – 9G schematically illustrate possible models and collections of views, for a body structure, in accordance with the present invention;

FIG. 10 illustrates, in flowchart form, a method of functional imaging, tailored for imaging from esophagus, and optimized with respect to the functional information gained about the body structure, in accordance with the present invention;

FIG. 11 schematically illustrates the process of modeling in two iterations, for zooming in on a pathological feature, in accordance with the present invention;

FIG. 12 illustrates, in flowchart form, a method of several iterations for zooming in on a pathological feature, when performing in vivo measurements, in accordance with the present invention;

FIGs. 13A – 13E schematically illustrate possible probe designs, and the process of obtaining views based on a model and a probe design, in accordance with the present invention;

FIG. 14 illustrates, in flowchart form, a method of selecting a probe design optimized with respect to information gained about a body structure, in accordance with the present invention;

FIG. 15 illustrates, in flowchart form, a method of selecting a probe design, based on the rate of data collection and other design considerations, in accordance with the present invention;

FIGs. 16A – 16L schematically illustrate the process of obtaining views with the radioactive-emission-measuring probe, based on a modeled volume, in accordance with the present invention;

FIGs. 16M – 16U schematically illustrate experimental results, obtained with the radioactive-emission-measuring probe, for a modeled volume having organ targets, in accordance with the present invention;

FIGs. 17A – 17L schematically illustrate various detecting units and blocks, which may be incorporated in probe designs;

FIGs. 18A – 18D schematically illustrate possible motions of a radioactive-emission-measuring probe, for a single detecting unit and a single block, in accordance with the present invention;

FIGs. 19A – 19E schematically illustrate other possible motions of a radioactive-emission-measuring probe, for a single block, in accordance with the present invention;

FIGs. 20A – 20H schematically illustrate possible motions of a radioactive-emission-measuring probe, having a plurality of pairs of radioactive-emission blocks;

FIGs. 21A – 21D schematically illustrate other possible motions of a radioactive-emission-measuring probe, having a plurality of pairs of radioactive-emission blocks;

FIGs. 22A – 22H schematically illustrate a radioactive-emission-measuring probe system, comprising a plurality of assemblies, each formed as the probe system of Figures 20A – 20H, in accordance with the present invention;

FIGs. 23A – 23D schematically illustrate a radioactive-emission-measuring-probe system, in accordance with the present invention;

FIGs. 24A – 24C schematically illustrate the modeling of a prostate as a process of two iterations, for zooming in on a pathology, in accordance with the present invention;

FIGs. 25A – 25E schematically illustrate the external appearance and the internal structure of the radioactive-emission-measuring probe for the prostate, in accordance with an embodiment of the present invention;

FIG. 26 illustrates further the internal structure of the radioactive-emission-measuring probe for the prostate, in accordance with an embodiment of the present invention;

FIG. 27 schematically illustrates the radioactive-emission-measuring probe for the prostate, integrated with an ultrasound probe, in accordance with another embodiment of the present invention;

FIG. 28 schematically illustrates an ultrasound wave impinging on a prostate, in accordance with the present invention;

FIGs. 29A - 29C illustrate the fusing of a radioactive-emission image and an ultrasound image, in accordance with the present invention;

FIG. 30 schematically illustrates the radioactive-emission-measuring probe for the prostate, integrated with a surgical needle, in accordance with another embodiment of the present invention;

FIGs. 31 and 32 schematically illustrates the operation of the surgical needle of FIG. 30; and

FIGs. 32 – 66F schematically illustrate various probes and applications, in accordance with the present invention

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is of systems, methods, and probes for functional imaging by radioactive-emission-measurements, specific to body structures, such as the prostate, the esophagus, the cervix, the uterus, the ovaries, the heart, the breast, the brain, and the whole body, and other body structures. The nuclear imaging may be performed alone, or together with structural imaging, for example, by x-rays, ultrasound, or MRI. Preferably, the radioactive-emission-measuring probes include detectors, which are adapted for individual motions with respect to the probe housings, to generate views from different orientations and to change their view orientations. These motions are optimized with respect to functional information gained about the body structure, by identifying preferred sets of views for measurements, based on models of the body structures and information theoretic measures. A second iteration, for identifying preferred sets of views for measurements of a portion of a body structure, based on models of a location of a pathology that has been identified, makes it possible, in effect, to zoom in on a suspected pathology. The systems are preprogrammed to provide these motions automatically.

The principles and operation of the radioactive-emission-measuring systems, probes and methods, according to the present invention, may be better understood with reference to the drawings and accompanying descriptions.

Before explaining at least one embodiment of the invention in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of the components set forth in the following description or illustrated in the drawings. The invention is capable of other embodiments or of being practiced or carried out in various ways. Also, it is to be

understood that the phraseology and terminology employed herein is for the purpose of description and should not be regarded as limiting.

Referring now to the drawings, Figures 5A – 5F present the principles of modeling, for obtaining an optimal set of views, in accordance with the present invention.

Figure 5A schematically illustrates a body section 230, having a region of interest (ROI) 200. The region of interest 200 may be associated with a body structure 215, with a specific radioactive-emission-density distribution, possibly suggestive of a pathological feature 213, termed herein an organ target 213. Additionally, there may be certain physical viewing constraints, associated with the region of interest 200.

We thus consider the following problem: how can we best identify an optimal and permissible set of views for radioactive-emission measurements of the region of interest 200, for reconstructing a three-dimensional image of it?

In accordance with the present invention, our approach is delineated in Figure 5C, by a method 205, as follows:

in a box 206: modeling the region of interest 200, as a model 250 of a volume U, possibly with one or several modeled organ targets HS, within anatomical constraints AC, as seen in Figure 5B;

in a box 207: obtaining an optimal and permissible set of views for the modeled volume U Figure 5B; and

in a box 208: applying the optimal set of views to the in-vivo region of interest 200 and the body structure 215 of Figure 5A.

It will be appreciated that the model 250 of the region of interest 200 may be based on general medical information of the body structure 215 and common pathological features associated with it. Additionally, the model may be based on information related to a specific patient, such as age, sex, weight, and body type. Furthermore, a structural image, such as by ultrasound or MRI, may be used for providing information about the size and location of the body structure 215 in relation to the body section 230, for generating the model 250.

Figures 5D – 5F schematically illustrate three types of the modeled organ targets HS, as follows:

i. a region of concentrated radiation, or a hot region, for example, as may be associated with a malignant tumor and as seen in Figure 5D;

ii. a region of low-level radiation, which is nonetheless above background level, for example, as may be associated with carcinoma and as seen in Figure 5E, and

iii. a region of little radiation, or a cold region, below the background level, for example, as may be associated with dead tissue and as seen in Figure 5F.

Referring further to the drawings, Figures 6A and 6B pictorially illustrate a view and viewing parameters associated with it, in accordance with definitions of the present invention.

Seen in Figure 6A is the volume U, subdivided into voxels u. The volume U is defined in a six-degree coordinate system $x;y;z;\omega;\theta;\sigma$ and has a point of origin $P0(x0; y0; z0; \omega0; \theta0; \sigma0)$. A detecting unit 12 is positioned at a location and orientation $P1(x1; y1; z1; \omega1; \theta1; \sigma1)$. The detecting unit 12 has a detector 91 of a specific detector material of a thickness t , and a collimator 96 of a diameter D and a length L, so as to define a collection angle δ.

Figure 6B schematically illustrates the emission rate of the volume U, as a function of time, given that a radioactive material of a specific half-life has been administered at a time T0.

A view may thus be defined as a group of nonzero probabilities of detecting a radioactive emission associated with all the voxels that form a sector S (Figure 6A).

A view is sometimes referred to as a projection, and the two terms are synonymous. Furthermore, a view defined over a sector S can be naturally extended to be defined over the set of all voxels, by simply associating a zero probability with every voxel outside the S. This makes possible the application of mathematical operations over the entire volume U.

A view is dependent on the following viewing parameters:

Location and orientation parameters:

A location and an orientation in a six-dimensional space, $P1(x1; y1; z1; \omega1; \theta1; \sigma1)$, with respect to the origin $P0(x0; y0; z0; \omega0; \theta0; \sigma0)$ of the volume U, in which the detecting unit 12 is positioned;

Detecting-unit parameters:

- The collection angle δ, which together with the location and orientation parameters, $P1(x1; y1; z1; \omega1; \theta1; \sigma1)$ with respect to the origin $P0(x0; y0; z0; \omega0; \theta0; \sigma0)$ define the sector S;
- The detector material, which affects the detector efficiency;
- The detector thickness t, which affects the detector's stopping power, hence, its efficiency; and
- The diameter of the detecting unit, or the effective diameter, calculated so as to produce a circle of the same area, when the geometry is not a circle;

Attenuation parameters:

Attenuation properties of all the voxels within the sector S, as they affect the probabilities that radioactive emissions from a specific voxel within the sector S will reach the detector, wherein different voxels within the sector S may have different attenuation properties, since several types of tissue may be involved;

Radiopharmaceutical parameters:

The half life $t_{1/2}$, of the radiopharmaceutical, the types of radioactive emission, whether gamma or beta, and the energies of the radioactive emission affect the probability of detection; and

Time parameters:

Given that T0 is the time of administrating the radiopharmaceutical, the time T1 since administration, and the duration of the measurement $\Delta T1$, affect the number of emissions that occur during the radioactive-emission measurement.

Some of these viewing parameters are fixed for a particular situation. Specifically, the tissue attenuation parameters are given. Additionally, the time T1 since administration of the radiopharmaceutical is generally governed by the blood pool radioactivity, since it is generally necessary to wait until the blood pool radioactivity dies out for low-level detection to be possible. For the remaining viewing parameters, optimization may be carried out.

The remaining viewing parameters may be divided into two categories:

i. viewing parameters in the design of a radioactive-emission-measuring probe;
ii. viewing parameters for an optimal set of views, for a given probe.

Viewing Parameters for an Optimal set of Views, for a Given Probe

Referring further to the drawings, Figures 7A – 7C schematically illustrate anatomical constraints, which may hinder measurements.

Figure 7A schematically illustrates the region of interest 200, for which a three-dimensional radioactive-emission image is desired. The region of interest 200 is in free space, with no constraints to limit accessibility to it. Thus, a radioactive-emission-measuring probe 210 may travel, for example, along tracks 202 and 204, and any other track, unhindered.

In Figure 7B, the region of interest 200 is associated with the body structure 215, such as a prostrate, in vivo. For obtaining a radioactive-emission image, the radioactive-emission-measuring probe 210 may be inserted transrectally, so as to travel in a rectum 206, for example, in the direction of an arrow 208. Its ability to image the prostrate is limited by anatomical constraints.

In Figure 7C, the region of interest 200 is associated with the body structure 215, such as a body structure, in vivo, and the radioactive-emission-measuring probe 210 may be an extracorporeal probe, which may perform radioactive-emission measurements from outside the body, on an extracorporeal surface 214, for example when moving along a track 212.

In each of these cases, it is desired that a reconstructed three-dimensional radioactive-emission image of the region of interest 200 be obtained, at a predetermined quality. This is achieved by predefining an optimal set of radioactive-emission measurement views, tailored to the specific organ 215 and optimized with respect to the information gained, regarding the body structure 215.

Referring further to the drawings, Figure 8 illustrates, in flowchart form, a method 300 for predefining a set of radioactive-emission measurement views, for functional imaging, tailored for imaging from esophagus and optimized with respect to the functional information gained, regarding the body structure 215, in accordance with the present invention. The method 300 comprises:

in a box 302: providing a model of the body structure 215, based on its geometry;

in a box 304: providing a model of anatomical constraints, which limit accessibility to the body structure;

in a box 306: providing a collection of views of the modeled body structure, obtained within the modeled anatomical constraints;

in a box 308: providing a scoring function, by which any set of at least one view, from a collection of views is scorable with a score that rates information, obtained from the modeled body structure by the set;

in a box 310: forming sets of views from the collection of views and scoring them, with the scoring function; and

in a box 312: selecting a set of views, from the collection of views, based on its score, as the predefined set of views.

The model of the body structure is based on anatomical knowledge regarding its size, shape, and weight. In fact different models may be provided, for example, for different ages, sexes, weights, and body types, such as heavy-built, medium-built, or small-built. In accordance with a first embodiment, the body structure is modeled assuming no radioactive emission throughout its volume. In accordance with other embodiments, the body structure may be modeled with one or more modeled organ targets, simulating different pathological features. Specifically, the modeled organ targets may be hot regions, of a radioactive-emission intensity, higher than the background level, regions of low-level radioactive-emission intensity, which is nonetheless above the background level, and cold regions, of a radioactive-emission intensity, lower than the background level. These may be distributed in accordance with medical records, which teach of sites within the body structure that may be more susceptible to certain pathologies.

Similarly, the model of anatomical constraints, which limit accessibility to the body structure, is based on anatomical knowledge, and different models may be provided, for example, for different ages, sexes, weights, and body types.

The collection of views may be obtained by several methods. It may be calculated analytically, for the modeled body, based on the view parameters. Additionally or alternatively, computer simulations of the modeled body and the view parameters may provide the collection of views. Additionally or alternatively, measurements may be performed, using a point source and a detecting unit of appropriate parameters, at different locations and orientations of the detecting unit, so as to simulate the desired geometries.

It will be appreciated that a combination of these may be used. For example, the measurements may be performed in air, but corrected analytically or by computer simulations, for tissue attenuation.

Referring further to the drawings, Figures 9A – 9G schematically illustrate possible models and collections of views, for an organ, in accordance with the present invention, as follows:

Figure 9A schematically illustrates four views, formed by sectors S1, S2, S3, and S4, through the volume U, which has an even distribution of radioactive emission.

Figure 9B schematically illustrates three views, formed by sectors S1, S2, and S3, through the volume U, which includes a modeled pathological feature, as the modeled organ target, HS.

Figure 9C schematically illustrates three views, formed by sectors S1, S2, and S3, through the volume U, which includes a modeled organ target, HS', of the same type as the modeled organ target HS, (that is, either a hot region or a cold region) but somewhat displaced along the x;y;z coordinate system. Additionally, the modeled organ target HS of Figure 9B is superimposed in Figure 9C, for illustrative purposes, in order to show the displacement delta1 between the modeled organ target HS of Figure 9B and the modeled organ target HS' of Figure 9C.

Figure 9D schematically illustrates three views, formed by sectors S1, S2, and S3, through the volume U, which includes a modeled organ target, HS", of the same type as the modeled organ targets HS and HS', but somewhat displaced along the x;y;z coordinate system from them. Additionally, the modeled organ targets HS of Figure 9B and HS' of Figure 9C are superimposed in Figure 9D, for illustrative purposes, in order to show the displacements delta2 and delta3, vis a vis HS" of Figure 9D.

Figure 9E schematically illustrates three views, formed by sectors S1, S2, and S3, through the volume U, which includes two modeled organ targets, HS1 and HS2;

Figure 9F schematically illustrates a pair of models of organs, as elliptical volumes, each with a slightly different distribution of modeled organ targets.

Figure 9G schematically illustrates four possible models of organs, as elliptical volumes, each with a slightly different distribution of modeled organ targets.

The modeled organ targets may be termed emittance models. In general, an emittance model is based on a particular radiopharmaceutical, which fixes both the rate of emission and the change in the rate of emission with time, determining the difference between the modeled organ target and the background level, as a function of time. To study the effect of different radiopharmaceuticals on the views, one

may provide different emittance models, based on different radiopharmaceuticals and different elapsed times from their administration.

The choice of an optimal set of views from among a collection of views, such as any of those illustrated in Figures 9A – 9E, is based on a scoring function, which rates different sets of views in terms of their information regarding the volume U, as provided by each set of views. The scoring function is based on information theoretic measures that rate the quality of the data which each set of views provides.

A brief description of the information theoretic measures, upon which the scoring function may be based, is as follows:

Uniformity:

The information theoretic measure of uniformity requires that the probability of detecting a radioactive emission from each voxel, by one of the views, be substantially equal for all the voxels, that is, substantially uniform for all the voxels.

This is illustrated in conjunction with Figure 9A. Basically, in one view, a voxel may have high influence on the counts that are measured, while in another, the same voxel may have low influence on the counts that are measured. For example, consider a voxel u(1;1;1), in relation to the views associated with the sectors S2 and S4. The voxel u(1;1;1) has high influence on the counts that are measured by the view associated with the sector S4, but low influence on the counts that are measured by the view associated with the sector S2. The aim under uniformity is to identify a set of views that will balance the influence of each voxel for the entire set of views.

Separability:

The information theoretic measure of separability rates resolution, or the ability of a set of views to distinguish between a pair of close models of the body structure, each having substantially identical dimensions, so as to define substantially identical volumes U, but with a slightly different distribution of modeled organ targets.

Consider for example, a pair of models of substantially identical volumes, as follows: The model of Figure 9B, which schematically illustrates the volume U, having the modeled organ target HS, whose center is at a location $(x;y;z)_{HS}$, and the model of Figure 9C, which schematically illustrates the volume U, having the modeled organ target HS', whose center is at a location $(x;y;z)_{HS'}$. In Figure 9C, the modeled

organ target HS of Figure 9B is superimposed, for illustrative purposes, in order to show the displacement between the two models. The displacement between the modeled organ targets is denoted as delta and may be measured, for example, in mm. In the present example, the displacement between the models of Figures 9B and 9C is delta1, along the x-axis.

An optimal set of views, from the standpoint of separability, is that which will best distinguish between HS of Figure 9B and HS' Figure 9C. Thus, a score, in terms of separability is given for the pair of models, and relates to a resolution as defined by the difference between the models of the pair. In the present example, the difference is delta1 along the x-axis, around the locations of HS and HS', so the score given by the information theoretic measure of separability, will relate specifically to a resolution as defined by delta1 along the x-axis, around the locations of HS and HS'. Other portions of the volume U and other directions may have different resolutions.

Additionally, consider the model of Figure 9D, which schematically illustrates the volume U, having the modeled organ target HS", whose center is at a location $(x;y;z)_{HS''}$, wherein HS" is displaced from HS of Figure 9B, along the z-axis, a displacement delta2. Additionally, HS" is displaced from HS' of Figure 9C, along the x- and z- axes, a displacement delta3. Figure 9D further includes the modeled organ targets HS of Figure 9B and HS' of Figure 9C, superimposed on it, for illustrative purposes, in order to show the displacements delta2 and delta3, vis a vis HS" of Figure 9D.

Scores, in terms of separability, may be given to all the paring combinations, that is the models of Figures 9B – 9C, relating to delta1; the models of Figures 9B – 9D, relating to delta2, and the models of Figures 9C – 9D, relating to delta3. An optimal set of views may be selected based on its average scores for all the pairing combinations; for example, the optimal set may be that whose average score for all the pairing combinations is the highest. Alternatively, a weighted average may be applied.

It will be appreciated that where more than one modeled organ target may be included in the volume U.

It will be further appreciated that a set of views may be selected so as to provide high resolution for portions of the volume U, known to be susceptible to

pathologies, and low resolution for portions of the volume U, known to be generally free of pathological features.

Figure 9F schematically illustrates a pair of models of organs, as elliptical volumes, each with a slightly different distribution of modeled organ targets, for identifying an optimal set of views in terms of separability.

Reliability:

The information theoretic measure of reliability rates repeatability in measurement, so that repeated reconstructions are not substantially different. Reliability may be scored with respect to a single model of a body structure, having a specific distribution of modeled organ targets, for example, any one of the models of Figures 9B – 9E. Yet, preferably, several models of substantially identical volumes are provided, for example, the four models of Figures 9B – 9E. Substantially identical sets of views may be applied to all the models and be scored with respect to reliability. The optimal set is selected based on its average score for the plurality of the models, for example, the optimal set may be that whose average score for the plurality of the models is the highest.

Figure 9G schematically illustrates four models of organs, as elliptical volumes, each with a slightly different distribution of modeled organ targets, for identifying an optimal set of views in terms of reliability.

A Weighted Combination:

A weighted combination of several information theoretic measures may also be used. For example, a plurality of models may be provided, all having substantially identical dimensions and volumes, as follows:

i. a first model of the volume U, free of modeled organ targets, as seen in Figure 9A, for scoring sets of views in terms of uniformity;

ii. at least one pair of models of the volume U, with slightly different distributions of modeled organ targets, as seen in any one of Figures 9B - 9C, 9B – 9D, and (or) 9C - 9D, for scoring sets of views in terms of separability;

iii. at least one model of the volume U, with a given distribution of modeled organ targets, as seen in any one of Figures 9B, 9C, 9D, and (or) 9E, for scoring sets of views in terms of reliability.

Identical sets of views may be applied to all the models of the volume U, and each view may be scored in terms of uniformity, separability, and reliability. An optimal set of views may be selected based on a summation of the three scores, or based on a weighted average of the three scores.

The Greedy Construction

Some approaches for selecting an optimal set are based on determining a required quality of reconstruction, and finding a set of views that meets that requirement. Others are based on fixing the size for the set (i.e., the number of views in the set) and maximize the quality of the reconstruction for the given set size. Still other approaches define both a desired size for the set and a desired quality of reconstruction and search for a set of the desired size, which meets the desired quality of reconstruction.

However, given a desired size for a set of views and a desired quality of reconstruction, while it may be possible to search through all possible sets of the desired size, scoring each, in order to identify the set that meets the desired quality, such a task may be monumental. For example, where the collection of views includes several thousand views, and a set size of 100 is desired, rating each combination of 100 views would be computationally impractical.

An alternative approach is the Greedy Construction. When applying the Greedy construction, an information theoretic measure is chosen, for example, separability, and an initial set of a minimal number of views is defined. The set is gradually built up, so that with every addition, a view is picked so as to maximize the chosen information theoretic measure of the set.

This may be illustrated in conjunction with Figure 9E. Given that separability is the chosen information theoretic measure, and an initial set of view S1 is defined, the additions of views S2 and S3 may then be compared in order to determine with

which of them is separability maximized. Intuitively, for the present example, the addition of S3 will maximize the chosen information theoretic measure of the set.

It will be appreciated that other scoring functions, as known, may similarly be used.

Performing Measurements

The power of the method of the present invention, of predefining a set of views based on a model of a body structure, using an information theoretic measure, so as to optimize the functional information from the views of the corresponding body structure, in vivo, becomes apparent when compared with the prior art alternatives. The prior art relies on obtaining random views, in vivo, or views dictated by anatomical constraints, with no rigorous approach to the manner by which they are chosen.

The method of the present invention, of predefining a set of views, based on a model of a body structure, using an information theoretic measure, so as to optimize the functional information from the views of the corresponding body structure, in vivo, is further illustrated hereinbelow, in conjunction with Figure 10.

Referring further to the drawings, Figure 10 illustrates, in flowchart form, a method 320 of functional imaging, tailored for imaging from esophagus, and optimized with respect to the functional information gained about the body structure, by using the predefined optimal set of views, in accordance with the present invention. The method 320 comprises:

in a box 322: providing a model of a body structure, based on its geometry;

in a box 324: providing a model of anatomical constraints, which limit accessibility to the body structure;

in a box 326: providing a collection of views of the modeled body structure, obtained within the modeled anatomical constraints;

in a box 328: providing a scoring function, by which any set of at least one view, from a collection of views is scorable with a score that rates information, obtained from the modeled body structure by the set;

in a box 330: forming sets of views from the collection of views and scoring them, with the scoring function;

in a box 332: selecting a set of views from the collection of views of the modeled body structure, based on its score, as the predefined set of views; and

in a box 334: performing radioactive-emission measurements of an in-vivo body structure that corresponds to the body structure that has been modeled, selectively at the predefined set of views.

It will be appreciated that the region of interest 200 may include an organ, such as a heart or a pancreas, a gland, such as a thyroid gland or a lymph gland, blood vessels, for example, the coronary artery or the pulmonary artery, a portion of an organ, such as an aorta or a left atrium of a heart, a bone, a ligament, a joint, a section of the body, such as a chest or an abdomen, or a whole body.

A still more powerful approach may be achieved by taking the method of the present invention through second and third iterations, so as to zoom in on suspected pathological features that are identified. Specifically, when a suspected pathological feature is identified, a second, inner region of interest, limited to the region of the pathological feature and its surrounding anatomical structure, can be identified and modeled. An optimal pathology set of views, specifically for the second, inner region of interest, may be predefined, based on information theoretic measures, as before. This is illustrated hereinbelow, in conjunction with Figures 11 and 12.

Referring further to the drawings, Figures 11 pictorially illustrates a method 340 for zooming in on a suspected pathological feature, as a process of two or more iterations, in accordance with the present invention, as follows:

In I: The region of interest 200, associated with the body structure 215, is defined for the body section 230.

In II: The model 250 of the volume U is provided for the region of interest 200, possibly with one or several of the modeled organ targets HS, and within the anatomical constraints AC, for obtaining the optimal set of views for the region of interest 200. The optimal set of views is then applied to the body section 230.

In III: When a suspected organ target 213 is identified, in vivo, by radioactive-emission measurements at the optimal set of views, a second, inner region of interest 200' is defined, encircling the suspected pathological feature.

In IV: A model 250' of a volume U' is provided for the second, inner region of interest 200', preferably, with at least one modeled organ target HS,

simulating the suspected organ target 213, for obtaining an optimal pathology set of views for the region of interest 200'. The second, pathology set of views is then applied to the body section 230.

Referring further to the drawings, Figure 12 illustrates, in flowchart form, the method 340, for zooming in on a suspected pathological feature of the body structure, as a process of two iterations, in accordance with the present invention. The method 340 comprises:

in a box 342: providing a model of a body structure, based on its geometry;

in a box 344: providing a model of anatomical constraints, which limit accessibility to the body structure;

in a box 346: providing a first collection of views of the modeled body structure, obtained within the modeled anatomical constraints;

in a box 348: providing a first scoring function, by which any set of at least one view, from a collection of views, is scorable with a score that rates information, obtained from the modeled body structure by the set;

in a box 350: forming sets of views from the first collection of views, and scoring them, with the first scoring function;

in a box 352: selecting a set of views from the first collection of views of the modeled body structure, based on its score, as the predefined set of views;

in a box 354: performing radioactive-emission measurements of an in-vivo body structure that corresponds to the body structure that has been modeled, selectively at the predefined set of views;

in a box 356: identifying a suspected pathological feature, in the in-vivo body structure;

in a box 358: providing a model of the suspected pathological feature, based on its location in the body structure and general medical knowledge;

in a box 360: providing a model of the anatomical constraints, which limit accessibility to the suspected pathological feature;

in a box 362: providing a second collection of views of the modeled suspected pathological feature, obtained within the modeled pathology's anatomical constraints;

in a box 364: providing a second scoring function;

in a box 365: forming sets of views from the second collection of views, and scoring them, with the second scoring function;

in a box 366: selecting a set of pathology views from the second collection of views, based on its score, as the predefined pathology set of views; and

in a box 368: performing radioactive-emission measurements of the suspected pathological feature, selectively at the predefined pathology set of views.

It will be appreciated that the model of the suspected pathological feature may be provided responsive to a patient's complaint, a physician's examination, or based on input from another imaging system, for example, x-rays, CT, MRI, ultrasound, and gamma scanning, for example, with a hand-held gamma camera, rather then based on the findings of the first set of measurements, of the step 356, hereinabove.

Design of a Radioactive-Emission-Measuring Probe

While the embodiments described in conjunction with Figures 5A – 12 relate to predefining a set of optimal views for a given radioactive-emission-measuring probe and a body structure, another side of the same coin relates to an optimal design of the radioactive-emission-measuring probe and probe system for the body structure, optimized with respect to functional information gained.

Thus, the embodiments described hereinbelow, in conjunction with Figures 13A – 15 illustrate methods of designing probes and probe systems, optimized with respect to information gained about a body structure.

Referring further to the drawings, Figures 13A – 13E schematically illustrate possible designs of the radioactive-emission-measuring probe 10, and the process of obtaining views for a given probe design, in accordance with the present invention.

Figures 13A – 13C schematically illustrate the radioactive-emission-measuring probe 10 as a radioactive-emission-measuring probe 226 arranged for measuring the radioactive-emission-density distribution of three bodies, U1, U2 and U3. The volume U1 of Figure 13A has been modeled with no modeled organ targets, in order to score the radioactive-emission-measuring probe 226 in terms of uniformity. The volume U2 of Figure 13B includes two modeled organ targets, HS1 and HS2, and may be used for scoring the radioactive-emission-measuring probe 226

in terms of reliability. The volume U3 of Figure 13C includes two modeled organ targets, HS1 and HS2', so as to form a pair with the volume U2 of Figure 13B, and the pair may be used for scoring the radioactive-emission-measuring probe 226 in terms of separability. Additionally, the volume U3 may be used to obtain a second score in terms of reliability, and the two reliability scores may be averaged. It will be appreciated that additional bodies, of different radioactive emission density distributions may be used, for obtaining additional scores in terms of reliability, and for forming additional pairs, for additional scores in terms of separability, wherein the scores in terms of each scoring function may be averaged. Additionally, the scores of the three functions may be combined, for example, as a sum, or as a weighted average. It will be appreciated that only one of the scoring functions, or only two of the scoring functions may be used. Additionally or alternatively, another scoring function or other scoring functions may be used.

According to the present example, the probe 226 has two detecting units 222A and 222B whose collimators are arranged in parallel. The two detecting units 222A and 222B are adapted for motion in the directions of ±x, within the probe 226, as shown by arrows 224 and 228, so as to provide coverage of a plane within the bodies U1 U2 and U3, in parallel sectors. Upon reaching the end of the travel in the +x direction, as shown by the arrow 224, the two detecting units 222A and 222B may be rotated in the direction of ω, as shown by an arrow 217, and return in the –x direction of the arrow 228. In this manner, complete coverage of the whole body is provided. A representative collection of views of the probe 226 may be defined as a set of views of the bodies U1, U2, and U3, taken at predetermined increments of Δx and Δω.

Intuitively, a set formed of parallel sectors may score poorly in terms of uniformity since radioactive emissions from voxels closer to the detecting unit have higher probabilities of being detected than radioactive emissions from voxels far from the detecting unit. Additionally, a set formed of parallel sectors may score poorly in terms of separability, since it cannot distinguish between two models, which only differ in the depth of a pathological feature, along the z-axis.

Figure 13D schematically illustrate the radioactive-emission-measuring probe 10 as a radioactive-emission-measuring probe 220, arranged for measuring the radioactive-emission-density distribution of the volume U2, which may be used for scoring the radioactive-emission-measuring probe 220 in terms of reliability.

The probe 220 has the two detecting units 222A and 222B, arranged to sweep a plane within the volume U2, in a windshield-wiper-like manner, along $\pm\theta$, as illustrated by arrows 216 and 218. When sweeping along $\pm\theta$ is completed, the detecting units 222A and 222B rotate a few degrees along ω, as illustrated by the arrow 217, and sweeping along $\pm\theta$ is repeated in the new orientation. In this manner, coverage of the whole volume U2 is performed, from two locations and a large plurality of orientations. A representative collection of views of the probe 220 may be defined as a set of views of the volume U2, taken at predetermined increments of $\Delta\theta$ and $\Delta\omega$.

The significance of the present embodiment, is as follows:

i. The different detecting units 222A and 222B provide views from different orientations; and

ii. The different detecting units 222A and 222B may change their view orientations.

A score may be applied to this set, based on the information theoretic measure of reliability.

It will be appreciated that similarly, the probe 220 may be arranged for measuring the radioactive-emission-density distribution of the volume U1 (Figure 13A) and of the volume U3 (Figure 13C), and possibly also of other bodies, in order to score the radioactive-emission-measuring probe 220 also in terms of uniformity and separability. The scores of the three functions may be combined, for example, as a sum, or as a weighted average. It will be appreciated that only one of the scoring functions, or only two of the scoring functions may be used. Additionally or alternatively, another scoring function or other scoring functions may be used.

Intuitively, the set of representative collection of views of the present example is likely to score more highly in terms of separability than that of the probe 226 of Figure 13A, as it provides views from different locations and orientations.

In Figure 13E the detecting units 222A and 222B of the probe 220 are further adapted for motion in the directions of $\pm x$, within the probe 220, as shown by the arrows 224 and 228.

Intuitively, the set of representative collection of views of the present example is likely to score more highly in terms of all three information theoretic measures,

than those of the probe of Figures 13A – 13C and of the probe of Figures 13D, as the present example provides views from a large plurality of locations and orientations.

In this manner, the information theoretic measures may be used for scoring representative collections of views of suggested probe designs, and an optimal probe design may be chosen based on this score, as described hereinbelow, in conjunction with Figures 14, hereinbelow.

Referring further to the drawings, Figure 14 illustrates, in flowchart form, a method 370 for identifying a probe optimized with respect to information gained about the body structure. The method 370 comprises:

in a box 372: providing a model of a body structure, based on its geometry;

in a box 374: providing a model of anatomical constraints, which limit accessibility to the body structure;

in a box 375: providing representative collections of views of the modeled body structure, within the modeled anatomical constraints, for different probe designs;

in a box 376: providing a scoring function, by which each representative collection of views, associated with a specific probe design, is scorable with a score that rates information, obtained from the body structure;

in a box 377: scoring the representative collections of views, with the scoring function; and

in a box 378: selecting a probe design, based on the score of its representative collection of views.

In this manner, a comparison of the quality of the data that may be produced by each probe design can be made. This analysis is important at the probe-design stage, in order to eliminate situations where views which are anatomically possible and which are desired from the standpoint of information theoretic measures, are unattainable because of probe design limitations. For example, the probe 190 of Figure 4C, hereinabove, cannot be used for the windshield-wiper-like motion, shown in Figure 13D, by the arrows 216 and 218; however, this type of coverage has proved very valuable. Enforcing the method 370 for probe design will favor another design.

Additionally, when selecting a probe design, it is generally desired to consider secondary issues, such as the rate of data collection, the cost of the probe, the

complexity of the design, for example, in terms of the number of motors and motion-transfer systems, and the like.

The rate of data collection is important both because it may be associated with patient discomfort and because it affects the number of patients that may be examined in a period of time. Where data collection with one probe design may take an hour and with another probe design it may take 10 minutes, the design of the faster probe is highly advantageous. Complexity and cost are important because they affect the accessibility of the general public to the probe.

Thus, a design scoring function may be provided, for rating each probe design with a design score, based on any one or a combination of the secondary issues. The design scoring function may be used for selecting a probe design from several that have been found acceptable in terms of the quality of the data, by the method 370 of Figure 14.

Referring further to the drawings, Figure 15 illustrates, in flowchart form, a method 380 of selecting a probe design, optimized with respect to information gained about a body structure and secondary issues, in accordance with the present invention. The method 380 comprises:

in a box 382: providing a model of a body structure, based on its geometry;

in a box 384: providing a model of anatomical constraints, which limit accessibility to the body structure;

in a box 385: providing representative collections of views of the modeled body structure, within the modeled anatomical constraints, for different probe designs;

in a box 386: providing a scoring function, by which each representative collection of views, associated with a specific probe design, is scorable with a score that rates information, obtained from the body structure;

in a box 387: scoring the representative collections of views, with the scoring function;

in a box 388: identifying several probe designs as acceptable, based on the scores of their representative collections of view;

in a box 390: providing a design scoring function, by which each probe design is scorable, based on the secondary issues;

in a box 392: scoring the acceptable probe designs with a design score;

in a box 394: selecting a probe design, based on its design score.

It will be appreciated other manners of combining the scoring function, which rates information, and the design scoring function, which rates secondary issues, are possible. For example, a combined scoring function, which takes both into account, may be used.

As will be shown, hereinbelow, in conjunction with Figures 19A – 22H, many different probe designs may provide substantially the same information, but are different in terms of their secondary considerations, that is, at different rates of data collection, different costs and different complexity of their designs, for example, in terms of the number of motors and motion-transfer systems. Thus these may score similarly in terms of functional information, and a design scoring function may be used to choose from amongst them.

Referring further to the drawings, Figures 16A – 16L schematically illustrate the process of obtaining views with the radioactive-emission-measuring probe 10, based on the model 250 of the volume U, in accordance with the present invention.

The views that are obtained by the present example may be used both as:

i. a collection of views for the volume U, from which an optimal set of views may be chosen, in accordance with the teachings of Figures 8, 10, and 12, hereinabove; and

ii. a representative collection of views of the probe 10, in accordance with the teachings of Figures 14 and 15, hereinabove.

Referring further to the drawings, Figures 16M – 16U schematically illustrate experimental results obtained with the radioactive-emission-measuring probe 10, in accordance with the present invention.

Figures 16M – 16O schematically illustrate line-source measurements of a wire source 101 in air, with a state of the art gamma camera and with the probes of the present invention.

As seen in Figure 16M, the wire source 101 is Cobolt -57, of 1mm in diameter and 200 mm in length.

Figure 16N illustrates an image 102 of a current state of the art gamma camera (not shown), for which a value of FWHM was 12.9 mm at a measuring distance of 10 cm from the source 101. About 5.1M counts were obtained after 337 seconds of counting. A 360-degree scan had been made.

Figure 16O illustrates images 107A and 107B of the probe 10 of the present invention, for which values of FWHM were 7.6 mm for the image 107A and 5.5 mm for the image 107B, at a measuring distance of 10 cm from the source 101. About 11M counts were obtained after 40 seconds of counting. In other words, for a counting time of about 1/10 that of the state of the art camera, the number of counts was more than twice that of the state of the art camera and the FWHM value was between 0.6 and 0.4 that of the state of the art camera, yielding a much sharper peak.

Figures 16P – 16R schematically illustrate line-source measurements of a wire source 101, in water, with a state of the art gamma camera and with the probes of the present invention.

As seen in Figure 16Q, of an image 104, results of a current state of the art gamma camera (not shown) were FWHM of 15.1 mm at a measuring distance of 15 cm from the source 101, and 1.1M counts after 337 seconds of counting.

As seen in Figure 16O, of an image 108, results of the probe 10 of the present invention were FWHM of 9.2 mm, at a measuring distance of 15 cm from the source 101, and 2.3M counts after 40 seconds of counting. Again, for a counting time of about 1/10 that of the state of the art camera, the number of counts were more than twice and the FWHM value was between 0.6 of the state of the art camera, yielding a much sharper peak.

Figures 16S and 16T schematically illustrate a Three-dimensional source, formed of two pellets 101A and 101B, in a Perspex phantom cylinder 105. The pellet 101A had a source to background ratio of 3:1 and the pellet 101B had a source to background ratio of 2:1. They were arranged as shown in Figure 16T, the distances being given in mm.

A series of coronal, sagital, and transverse images were taken, by a state of the art gamma camera and by the probe of the present invention. A total of 2,500 counts were obtained, for which the state of the art camera required 9 minutes, and the probe of the present invention required 1 minute.

As seen on Figure 16U, the state of the art camera provided little resolution, while the probe of the present invention resolved both the 3:1 source 101A and the 2:1 source 101B, as well as border artifacts and background rings.

EXAMPLES OF PROBE SYSTEMS

Reference is now made to the following examples of radioactive-emission-measuring probes and probe systems, for the comparative study taught in conjunction with Figures 14 and 15.

EXAMPLE 1

Referring further to the drawings, Figures 17A – 17H schematically illustrate detecting units 12 and blocks 90 that may be considered for possible probe designs.

Figures 17A and 17B schematically illustrate side and top views, respectively, of the basic detecting unit 12 (see also Figure 1A), having a detector 91 and a wide-bore collimator 96, formed as a tube, of a collection angle δ1.

Figures 17C and 17D schematically illustrate side and top views, respectively, of the detecting unit 12, with the collimator 96 formed as a wide angle collimator, of a collection angle δ2.

Figures 17E and 17F schematically illustrate side and top views, respectively, of the block 90 (see also Figure 1B) of the detecting units 12, with the collimator 96 formed as a grid, and each of the detecting unit 12 having a collection angle δ3. As few as two or four, and as many as a hundred or several hundred of the detecting units 12 may be included in the block 90.

Figures 17G and 17H schematically illustrate side and top views, respectively, of the block 90 of the detecting units 12, with the collimator 96 formed as a grid, with two sizes of the detecting units 12, as follows: small detecting units 94A, of collection angles δ4, at the center of the grid, and large detecting units 94B, of collection angles δ5, at the periphery. It will be appreciated that other arrangements of detecting units of different sizes may be used.

It will be appreciated that a combination of these may be used. For example, the block 90 may include wide-angle collimators at the periphery and normal collimators of 90-degrees at the center.

Figures 17I – 17L schematically illustrate the block 90, wherein the detector 91 is a single-pixel scintillation detector, such as NaI(Tl), LSO, GSO, CsI, CaF, or the like, operative with photomultipliers 103.

As seen in Figure 17I, the block 90, having proximal and distal ends 109 and 111, respectively, vis a vis an operator (not shown), is formed of the scintillation

detector 91, of a single pixel, and the collimators 96, to create the detecting units 12. A plurality of photomultipliers 103 is associated with the single pixel scintillation detector 91, and with proper algorithms, as known, their output can provide a two dimensional image of the scintillations in the single pixel scintillation detector 91. In essence, this is an Anger camera, as known.

The distal view 111 of the collimator grid is seen in Figure 17J.

Two optional proximal views 109 of the photomultipliers 103 are seen in Figures 17K and 17L, as a square grid arrangement, and as an arrangement of tubes.

EXAMPLE 2

Referring further to the drawings, Figures 18A and 18B schematically illustrate the radioactive-emission-measuring probe 10, of the single detecting unit 12 (see Figures 1A and 17A). The single detecting unit 12 has a motion with respect to the housing 20, which is a combination of a rotational motion around the x-axis, in the direction of ω, denoted by an arrow 44, and a translational motion along the x-axis, denoted by an arrow 46.

As a consequence, a spiral trace 48 is formed, for example, on an inner surface of a body lumen 232, as seen in Figure 18B.

Preferably, the motions of the detecting unit 12 are contained within the housing 20, so that the external surface of the probe 10 remains stationary. The external surface of the probe may be formed of a carbon fiber, a plastic, or another material, which is substantially transparent to nuclear radiation.

EXAMPLE 3

Referring further to the drawings, Figures 18C and 18D schematically illustrate the radioactive-emission-measuring probe 10, of the single block 90 (Figures 1B and 17E). Note that all the detecting units 12 of the single block 90 move as a single body. The single block 90 has a motion with respect to the housing 20, which is a combination of the rotational motion around the x-axis, in the direction of ω, denoted by the arrow 44, and the translational motion along the x-axis, denoted by the arrow 46.

As a consequence, a plurality of spiral traces 49 is formed, for example, on an inner surface of a body lumen, as seen in Figure 18D.

Preferably, the motions of the block 90 are contained within the housing 20, so that the external surface of the probe 10 remains stationary, wherein the external surface of the probe is substantially transparent to nuclear radiation.

EXAMPLE 4

Referring further to the drawings, Figures 19A – 19E schematically illustrate the radioactive-emission-measuring probe 10, of the single block 90 of a plurality of the detecting units 12.

For understanding the motion of the probe 10 of the present example, it is desirable to define a cylindrical coordinate system of a longitudinal axis, x, and a radius r, wherein the motion around the longitudinal axis, x, is denoted by ω, while the motion around the radius r is denoted by ϕ.

The single block 90 has a motion with respect to the housing 20, which is performed in steps, as follows:

i. the windshield-wiper like oscillatory motion, around the radius r, in the direction of $\pm\phi$, as denoted by the arrow 50;

ii. the translational motion along the x-axis, by an amount Δx, to a new measuring position, as denoted by the arrow 46;

iii. after traversing the length of the probe, a rotational motion around the x-axis, in the direction of ω, by an amount $\Delta\omega$, as denoted by the arrow 44, in order to perform the same measurements at a new measuring position of ω.

As a consequence, a plurality of broken line traces 59 are formed, as seen in Figure 19E.

Preferably, the motions of the block 90 are contained within the housing 20, so that the external surface of the probe 10 remains stationary, wherein the external surface of the probe is substantially transparent to nuclear radiation.

EXAMPLE 5

Referring further to the drawings, Figures 20A – 20H schematically illustrate the radioactive-emission-measuring probe 10, having at least one pair, or a plurality of pairs of blocks 90, adapted for the windshield-wiper like oscillatory motion, around the radius r, as denoted by the arrows 50. The oscillatory motions may be synchronized in an antipodal manner, so as to be diametrically opposed to each other,

as shown in Figures 20B and 20E, by the arrows 54, and as shown in Figures 20C and 21F by the arrows 56. It will be appreciated that the oscillatory motions need not be synchronized in an antipodal manner. Rather, all the blocks 90 may move together, or each block 90 may move independently. It will be appreciated that an odd number of blocks 90 is also possible.

Additionally, a rotational motion of the housing 20, around the x-axis in the direction of ω, an amount $\Delta\omega$, to a new measuring position along ω, is provided, after each step of the oscillatory motion, as shown in Figure 20D, by an arrow 52.

The resultant traces are the plurality of broken line traces 59, as seen in Figure 20G.

In essence, the probe 10 of Figures 20A – 20H provides views which are essentially the same as those of Figures 19A – 19E, but in a more efficient way, since a plurality of blocks is involved.

In accordance with the present example,

i. The different blocks 90 provide views from different orientations; and

ii. The different blocks 90 may change their view orientations.

Preferably, the motions of the blocks 90 are contained within the housing 20, so that the external surface of the probe 10 remains stationary, wherein the external surface of the probe is substantially transparent to nuclear radiation.

In particular, as seen in Figure 20H, an internal housing 21 may contain all the blocks 90, so that they may be moved together by the motion provider 76, as a single structure, while housing 20 and the external surface of the probe 10 remain stationary.

The operational manner of the probe 10 of Figures 20A – 20H is described in conjunction with Figure 23C, hereinabove.

It will be appreciated that the single detecting units 12 may be used in place of the single blocks 90.

EXAMPLE 6

Referring further to the drawings, Figures 21A – 21D schematically illustrate the radioactive-emission-measuring probe 10, having at least one pair, or a plurality of pairs of blocks 90, adapted for the windshield-wiper like oscillatory motion, around the radius r, as denoted by the arrow 50. The oscillatory motions are preferably synchronized in an antipodal manner, so as to be diametrically opposed to each other,

as in Figures 20A – 20H. It will be appreciated that the oscillatory motions need not be synchronized in an antipodal manner. Rather, all the blocks 90 may move together, or each block 90 may move independently. It will be appreciated that an odd number of blocks 90 is also possible.

Additionally, a rotational motion of each of the blocks 90 around the x-axis, in the direction of ω, an amount Δω, to a new measuring position along ω, is provided, after each step of the oscillatory motion, as shown in Figure 21B, by the arrows 44. This is unlike Figure 20D, wherein the internal housing 21 moved as a single unit, as shown in Figure 20D and 20H.

The resultant traces are the plurality of broken line traces 59, as seen in Figure 21D. In essence, the probe 10 of Figures 21A – 21D provides views which are essentially the same as those of Figures 19A – 19E, and of Figures 20A – 20H, but in a different manner.

In accordance with the present example,

i. The different blocks 90 provide views from different orientations; and

ii. The different blocks 90 may change their view orientations.

Preferably, the motions of the blocks 90 are contained within the housing 20, so that the external surface of the probe 10 remains stationary, wherein the external surface of the probe is substantially transparent to nuclear radiation.

It will be appreciated that the detecting units 12 may be used in place of the blocks 90.

EXAMPLE 7

Referring further to the drawings, Figures 22A – 22H schematically illustrate a radioactive-emission-measuring probe 95, comprising a plurality of assemblies 92, each assembly 92 being similar in construction to the probe 10 of Figure 20H, in accordance with the present invention.

The plurality of assemblies 92 are preferably arranged in parallel, and their rotational motions, around the x-axis, may be synchronized in an antipodal manner, so as to be diametrically opposed to each other, as shown in Figures 22C, by arrows 62, and in Figure 22G, by arrows 64. It will be appreciated that the rotational motion around the x-axis need not be synchronized in an antipodal manner, and may be performed in parallel, or independently.

Thus, the resultant traces are a large plurality of the broken line traces 66 and 68, as seen in Figures 22D and 22H.

In essence, the probe 95 of Figures 22A – 22H provides views which are essentially the same as those of Figures 19A – 19E, 20A – 20H, and 21A – 21D, but far more efficiently, since a plurality of assemblies are involved.

In accordance with the present example,

i. The different blocks 90 provide views from different orientations;

ii. The different blocks 90 may change their view orientations;

iii. The different assemblies 92 provide views from different orientations; and

iv. The different assemblies 92 may change their view orientations.

The operational manner of the probe 95 is described in conjunction with Figure 23D, hereinbelow, for the at least two assemblies 92A and 92B.

Preferably, the motions of the blocks 90 and of the assemblies 92 are contained within the housing 20, so that the external surface of the probe 95 remains stationary, wherein the external surface of the probe 95 is substantially transparent to nuclear radiation.

It will be appreciated that probe 95 may include a plurality of assemblies 92, which are not parallel to each other. For example, the assemblies 92 may be at right angles to each other, or at some other angle.

It will be appreciated that the assemblies 92 may include the detecting units 12 rather then the blocks 90.

Example 8

Having designed a radioactive-emission-measuring probe capable of obtaining a collection of views, and having predefined a set of views, which is optimal for a body structure, based on its model, the task of performing measurements, selectively at the predefined set of views, would be quite impossible if it were to be performed manually. Generally, between several hundreds and several thousands of views are taken, and manually tuning each to a predetermined location, orientation, and possibly also duration would be impractical. Therefore, the probe and method of the present invention are operative with an overall system, in which computer controlled motion providers govern the motions of the detecting units or of the overall probe. The computer may be any one of a personal computer, a laptop, a palmtop, or another

computer, adapted for communication with the probe, or a microcomputer, built into the probe. Additionally, a combination of a microcomputer, built into the probe, and an external computer such as a personal computer, a laptop, a palmtop, or the like, may be used.

Preferably, before measurements are performed, personal details are fed into the computer, and the models of the body structure and anatomical constraints are adapted to these details. The personal details may include age, sex, weight, body type, and the like.

Referring further to the drawings, Figures 23A – 23D schematically illustrate radioactive-emission-measuring-probe systems 400 in accordance with the present invention.

As seen in Figure 23A, the probe system 400 includes the probe 10, having a controller 404, in communication with one or several motion providers 76, for sending signals of views' locations and orientations to the one or several motion providers 76. The one or several motion providers 76, in turn, govern the motions of one or several of the detecting units 12. The one or several of the detecting units 12 collect the measurements at the predefined locations and orientations and communicate the data to the controller 404. Signals of new locations and orientations are then communicated by the controller 404 to the one or several motion providers 76. Each of the motion providers 76 may control the motion of one of the detecting units 12 or of a plurality of the detecting units 12.

Preferably, the controller 404 registers the location and orientation of each of the detecting unit 12 as it moves. Additionally or alternatively, a position-tracking device may be associated with each of the detecting units 12.

Preferably, a position-tracking device 418 is associated with the probe 10 as a whole, for registering its position with respect to the body, for example, with respect to the body structure 215 (Figure 5A).

A power supply 410 powers the probe 10. Alternatively, power may be supplied from the grid.

Preferably, a transceiver 402, or a transmitter 402, reports the measurements to an external computer. Alternatively, a cable may be used. Alternatively, the controller 404 includes a microcomputer, or the like, and performs the data analysis.

Additionally, the transceiver 402 may be adapted to receive input data relating to the personal details of the patient, such as the age, sex, weight, body type, and the like, in order to adjust the model of the body structure, hence the locations and orientations of the predefined, optimal set of views, to the particular patient.

Furthermore, the transceiver 402 may be adapted to receive input data from an ultrasound imager, for providing information such as location, size of the body structure and the like, by ultrasound imaging, in order to adjust the model of the body structure, hence the locations and orientations of the predefined, optimal set of views, to the particular patient.

Preferably, the motion of the one or several motion providers 76 relates to motion of the detecting units 12 with respect to the probe housing 20, for example, as taught in conjunction with Figure 13E, by the motion of detecting units 222A and 222B, with respect to the housing 220, as shown by the arrows 216 and 218.

Alternatively or additionally, the motion of the one or several motion providers 76 may relate to motion of the probe housing as a whole, with respect to the body structure 215 (Figure 5A), for example, as taught in conjunction with Figure 13E, by the motion the probe 220, as shown by the arrows 217 and 228.

It will be appreciated that the controller 404, while being part of the system 400, need not part of the actual probe 10. Rather it may be an external computer, communicating with the probe 10 either by cables or via a transceiver.

As seen in Figure 23B, the probe 10 includes the blocks 90, each comprising a plurality of the detecting units 12, each block 90 moving as a single body.

As seen in Figure 23C, the individual motion of the blocks 90 is governed by a secondary motion provider 78. Additionally, all of the blocks 90 form an assembly 92, which moves by the motion provider 76, for example, within an internal housing 21, as illustrated hereinbelow in conjunction with Figure 20H. For example, the secondary motion provider 78 may provide the motion described by the arrows 50 of Figures 20B and 20C or 20F and 20F, hereinbelow while the motion provider 76 may provide the motion described by the arrow 52 of Figure 20H, hereinbelow.

It will be appreciated that the multiple motions may be provided to the detecting units 12, rather then to the blocks 90.

It will be appreciated that a tertiary motion provider may also be used and that many arrangements for providing the motions are possible, and known.

As seen in Figure 23D, at least two assemblies 92 may be provided, each with a dedicated motion provider 76 and a dedicated secondary motion provider 78. It will be appreciated that the multiple motions may be provided to the detecting units 12, rather then to the blocks 90. It will be appreciated that tertiary motion providers may also be used and that many arrangements for providing the motions are possible, and known.

In the example of Figure 23D, the controller 404, while being part of the system 400, is not part of the actual probe 10. For example, it may be an external computer, communicating with the probe 10 either by cables or via a transceiver.

EXAMPLES OF PROBE SYSTEMS FOR SPECIFIC APPLICATIONS

Reference is now made to the following examples of radioactive-emission-measuring probes and probe systems, for specific applications.

EXAMPLE 9

Referring further to the drawings, Figures 24A - 32 schematically illustrate the radioactive-emission-measuring probe 10, for the prostate, in accordance with an embodiment of the present invention.

Figures 24A – 24C schematically illustrate the modeling of a prostate and a location of a pathology, as a process of two iterations, for zooming in on the pathology, in accordance with the present invention.

Figure 24A schematically illustrates a body section 230, which includes a prostate 260, which has sections 262, 264 and 266, and a pathology 265 in section 264. Additionally, the body section 230 includes a rectum 268, from which the prostate 260 may be viewed.

Figure 24B schematically illustrates the model 200 of the body section 230, including the prostate 260, of sections 262, 264 and 266, and the rectum 268. An optimal set of views is predefined based on the model 200 and a first scoring function. The first scoring function may be based on regions of interest similar to the pathology 265, as known, from medical records of common pathologies. Measurements of radioactive emission are then taken at the predefined views, in vivo, for the prostate 260.

As seen in Figure 24C, upon discovering the pathology 265, by the in-vivo measurements, a second model 250 of the section 264 is made, for zooming in on the pathology 265, and a second optimal set of views is predefined, based on the second model 250 of the section 264 and a second scoring function, for zooming in on the pathology 265. Measurements of radioactive emission are then taken at the predefined second set of views, in vivo, for the section 264 and the pathology 265.

It will be appreciated that the first and second scoring functions may be based on any one of or a combination of the information theoretic measures of uniformity, separability, and reliability. It will be further appreciated that the first and second scoring functions need not be the same.

Figures 25A – 25E illustrate an external appearance and an internal structure, of the probe 10. The radioactive-emission-measuring probe 10 for the prostate has an extracorporeal portion 80 and an intracorporeal portion 82, which is adapted for insertion to a rectum. The housing 20 of the intracorporeal potion 82 is preferably shaped generally as a cylinder and defines a longitudinal axis along the x axis, and a radius, perpendicular to the longitudinal axis. The intracorporeal portion 82 preferably includes two pairs of assemblies 90, arranged in the housing 20. It will be appreciated that another number of assemblies, for example, a single pair, or three pairs, is similarly possible. An odd number of assemblies is similarly possible. In essence, the probe 10 of the present example is analogous to the probe 10 of Figure 23C and Figures 20A - 20H, and particularly, to Figure 20H. The rotational motion, in the direction of the arrow 52 of Figure 20H, is provided by a motor 88 (Figure 25C) and a main shaft 85. The motor 88 may be an electric motor, for example, a servo motor. The motor 88 and main shaft 85, together, form a motion provider 76 for the rotational motion in the direction of the arrow 52 of Figure 20H. The oscillatory motion, in the direction of the arrows 50 of Figures 20B - 20C and 20E - 20F, is provided by a secondary motor 86, a secondary shaft 84 and a motion transfer link 74. The secondary motor 86 may also be an electric motor, for example, a servo motor. The secondary motor 86, secondary shaft 84 and the motion transfer link 74, together, form the secondary motion provider 78, in the direction of the arrows 50 of Figures 20A - 20H.

The significance of the present embodiment, is as follows:

i. The different assemblies 90 provide views from different orientations; and

ii. The different assemblies 90 may change their view orientations independent of each other.

It is important to point out that during the operation of the probe 10, the external surface of the intracorporeal portion 82 (Figure 25D - 25E) remains stationary, while the inner housing 21 (Figure 25C) rotates around the x axis. The external surface of the intracorporeal portion 82 may be formed of a carbon fiber, a plastic, or another material, which is substantially transparent to nuclear radiation.

Figure 25E illustrates further the internal structure of the radioactive-emission-measuring probe for the prostate, in accordance with an embodiment of the present invention, showing the assemblies 90 within the housing 20. Each assembly may be a single detecting unit 12, or a plurality of the detecting units 12, for example, 36 of the detecting units 12, for example, as an array of 6X6, or 99 of the detecting units 12, for example, as an array of 11 X 9, or another number of the detecting units 12, arranged as an array or arranged in another geometry.

Referring further to the drawings, Figure 26 illustrates further the internal structure of the radioactive-emission-measuring probe for the prostate, in accordance with an embodiment of the present invention, showing the oscillatory motion (in the direction of the arrows 50 of Figures 20A, and 20C) of the assemblies 90 within the housing 20.

Figures 27 – 30C schematically illustrate the radioactive-emission-measuring probe 10, for the prostate, in accordance with another embodiment of the present invention. In accordance with the present embodiment, the probe 10 further includes an ultrasound transducer 85, arranged, for example, at the tip of the intracorporeal portion 82.

Figure 27 illustrates the external appearance of the probe 10 with the ultrasound transducer 85 at its tip.

Figure 28 illustrates the ultrasound wave 87, impinging on the prostate 260.

Figures 29A - 29C illustrate the fusing of a radioactive-emission image and an ultrasound image, to illustrate the functional information of the radioactive-emission image with the structural information of the ultrasound image. The ultrasound image is seen in Figure 29A, the radioactive-emission image is seen in Figure 29B, and the fusing of the two is seen in Figure 29C.

Figures 30 – 32 schematically illustrate the radioactive-emission-measuring probe 10, for the prostate, in accordance with another embodiment of the present invention. In accordance with the present embodiment, the probe 10 further includes an ultrasound transducer 85, and a surgical needle 83, in a needle guide 31, arranged alongside the probe 10, for obtaining a biopsy or for other minimally invasive procedures.

Figure 30 schematically illustrates the surgical needle 81 as it penetrates the prostate 260 from the rectum 268.

Figures 31 and 32 schematically illustrate the manner of guiding the needle 31. A track 89 shows the surgeon the direction of the needle, while the probe 10 produces the functional image of the pathology 265 in the prostate 260. By moving the probe 10, manually, the surgeon can align the track 89 with the pathology 265, as shown in Figure 32. Once aligned, he can eject the needle 83, as shown in Figure 30.

EXAMPLE 10

Referring further to the drawings, Figure 33 pictorially illustrates the method 340 for zooming in on a suspected pathological feature in a woman's reproductive system, as a process of two or more iterations, in accordance with the present invention, as follows:

As seen in Figure 33, the method 340 may be described, pictorially, as follows:

In I: The region of interest 200, associated with the woman's reproductive system 215, is defined for the body section 230.

In II: The model 250 of the volume U, is provided for the region of interest 200, possibly with one or several of the modeled organ targets HS, and within the anatomical constraints AC, for obtaining the optimal set of views for the region of interest 200. The optimal set of views is then applied to the body section 230.

In III: When a suspected organ target 213 is identified, in vivo, by radioactive-emission measurements at the optimal set of views, a second, inner region of interest 200' is defined, encircling the suspected pathological feature.

In IV: A model 250' of a volume U' is provided for the second, inner region of interest 200', preferably, with at least one modeled organ target HS,

simulating the suspected organ target 213, for obtaining an optimal pathology set of views for the region of interest 200'. The second, pathology set of views is then applied to the body section 230.

Referring further to the drawings, Figures 34A – 34R schematically illustrate radioactive-emission measuring probes 600, tailored for imaging the woman's reproductive system and optimized with respect to the functional information gained, regarding the body structures of the woman's reproductive system, such as the cervix 274, the uterus 276, the ovaries 278, and the fallopian tubes 280, in accordance with preferred embodiments of the present invention.

Figure 34A schematically illustrates the basic radioactive-emission measuring probe 600, for a body lumen, for example, the vagina 272, the cervix 274, the uterus 276, the rectum 292, or the sigmoid colon 294. The probe 600 includes an extracorporeal portion 610, which preferably comprises a control unit, and an intracorporeal portion 630, having proximal and distal ends 631 and 633, with respect to an operator (not shown).

The control unit of the extracorporeal portion 610 may include control buttons 612 and possibly a display screen 614, and may provide connections with a computer station. It may receive power from a grid or be battery operated. The control unit of the extracorporeal portion 610 may further include a computer or a microcomputer. It will be appreciated that the control unit may be incorporated with the intracorporeal section 630, and operated remotely.

The intracorporeal portion 630 defines a cylindrical coordinate system of x;r, wherein x is the longitudinal axis. The plurality of blocks 90 along the length of the intracorporeal portion 630 is housed in an inner housing 21 (Figure 20H).

Each of the blocks 90 is adapted for the windshield-wiper like oscillatory motion, around the radius r, as denoted by the arrows 50. The oscillatory motions may be synchronized in an antipodal manner, so as to be diametrically opposed to each other, as shown hereinabove in Figures 20B and 20E, by the arrows 54, and as shown hereinabove in Figures 20C and 20F by the arrows 56. However, other motions are also possible. For example, the blocks 90 may move together, or independently. It will be appreciated that an odd number of blocks 90 is also possible.

Additionally, the inner housing 21 is adapted for rotational motion around the x-axis, in the direction of ω, wherein after each step of oscillatory motion at a certain

orientation of ω, the inner housing rotates by a step to a new orientation of ω, and the oscillatory motion is repeated.

As a consequence, a plurality of broken line traces 59 are formed, in the body section 230, as seen in Figure 34J.

Preferably, the controller or the computer registers the locations and orientations of each detecting unit or block and correlates the measurements with the corresponding positions and orientations.

A position-tracking device 635 may also be used, for providing information regarding the position of the probe 600 relative to a known reference. For example, if a structural scan, or another scan by another imager has been made, the position-tracking device 635 may be used to register the previous scan with the measurements of the probe 600.

It will be appreciated that the probe 600 may include detecting units 12 rather then blocks 90.

Preferably, the housing 20 remains stationary and is substantially transparent to nuclear radiation, formed, for example, of a hydrocarbon material.

The intracorporeal portion 630 may further include dedicated electronics 634 and motion providers 636, such as miniature motors and motion transfer systems, as known.

Figures 34B and 34C schematically illustrate side and distal views, respectively, of the radioactive-emission measuring probe 600, having an ultrasound imager 640 at its distal tip 633. The ultrasound imager 640 may provide a structural image which may be correlated with the functional image. Additionally, it may be used for providing the size and location of the body structure for modeling. Furthermore, it may be used for providing attenuation correction to the radioactive emission measurements.

Figures 34D and 34E schematically illustrate side and distal views, respectively, of the radioactive-emission measuring probe 600, having an MRI imager 642 at its distal tip 633. The MRI imager 642 may provide a structural image which may be correlated with the functional image. Additionally, it may be used for providing the size and location of the body structure for modeling. Furthermore, it may be used for providing attenuation correction to the radioactive emission measurements.

Figures 34F - 34I schematically illustrate the radioactive-emission measuring probe 600, having a distal block 90A at its distal tip 633. The distal block 90A at the distal tip is also adapted for oscillatory motion, but about the x-axis, as seen by an arrow 53. When combined with the rotational motion around the x-axis, it produces traces 55 in the shape of a star, in the body section 230, as seen in Figure 34K.

It will be appreciated that a single distal detecting unit may be employed in place of the distal block 90A.

Figures 34L – 34Q schematically illustrates the radioactive-emission measuring probe 600, for a body lumen, having the distal block 90A at its distal tip 633, adapted for a deployed and a retracted position, and for oscillatory motion about the x-axis, when deployed. The probe 600 further has the ultrasound imager 640 at its distal tip 633, as a ring, similarly having a deployed and a retracted position.

Figures 34N – 34P illustrate the distal block 90A deployed, and the ultrasound imager 640 retracted. In this manner, the ultrasound imager 640 does not obstruct the oscillatory motion of the distal block 90A at the distal tip 633.

Figure 34Q illustrates the distal block 90A retracted and the ultrasound imager deployed so the distal block 90A does not obstruct the view of the ultrasound imager. It will be appreciated that the ultrasound image is to be taken once, from the distal tip 633, while the radioactive-emission measurements are to be taken at a plurality of orientations, from the distal tip 633.

Figure 34R illustrates the probe 600 with a cable 620 connecting the intracorporeal portion 630 and the extracorporeal portion 610, for example, for imaging the ovaries and the fallopian tubes from the sigmoid colon.

It will be appreciated that the probes 600 of the present invention may also be moved manually, both linearly, into the body lumen and rotationally, around its longitudinal axis, preferably while the position-tracking device 635 (Figure 34A) registers its position.

It will be appreciated that a probe with a single block or a single detecting unit may also be used.

EXAMPLE 11

Referring further to the drawings, Figures 35A – 35R schematically illustrate radioactive-emission measuring probes 600, adapted for the esophagus, in accordance with preferred embodiments of the present invention.

Figure 35A schematically illustrates the basic radioactive-emission measuring probe 600, for the esophagus. The probe 600 includes an extracorporeal portion 610, which comprises a control unit, and an intracorporeal portion 630, having proximal and distal ends 631 and 633, with respect to an operator (not shown). A flexible cable 620 connects between them.

The control unit 610 may include control buttons 612 and possibly a display screen 614, and may provide connections with a computer station. It may receive power from a grid or be battery operated. The control unit 610 may further include a computer or a microcomputer.

The intracorporeal portion 630 is constructed essentially as the probe 10 of Figures 23C and Figures 20A – 20H, and specifically, Figure 20H.

Thus, the intracorporeal section 630 defines a cylindrical coordinate system of x;r, wherein x is the longitudinal axis. The plurality of blocks 90 along the intracorporeal portion 630 is housed in an inner housing 21.

Each of the blocks 90 is adapted for the windshield-wiper like oscillatory motion, around the radius r, as denoted by the arrows 50. The oscillatory motions may be synchronized in an antipodal manner, so as to be diametrically opposed to each other, as shown hereinabove in Figures 20B and 20E, by the arrows 54, and as shown hereinabove in Figures 20C and 20F by the arrows 56. However, other motions are also possible. For example, the blocks 90 may move together, or independently. It will be appreciated that an odd number of blocks 90 is also possible.

Additionally, the inner housing 21 is adapted for rotational motion around the x-axis, in the direction of ω, wherein after each step of oscillatory motion at a certain orientation of ω, the inner housing rotates by a step to a new orientation of ω, and the oscillatory motion is repeated.

As a consequence, a plurality of broken line traces 59 are formed, in the body section 230, as seen in Figure 35J.

Preferably, the controller or the computer registers the locations and orientations of each detecting unit or block and correlates the measurements with the corresponding positions and orientations.

A position-tracking device 635 may also be used, for providing information regarding the position of the probe relative to a known reference.

It will be appreciated that the probe 600 may include detecting units 12 rather then blocks 90, for example, as taught in conjunction with Figures 20A – 20G.

Preferably, the housing 20 remains stationary, and has an external surface, which is substantially transparent to nuclear radiation.

A ball bearing 632 may be used at the connecting point with the cable 620, to enable the rotational motion.

The intracorporeal section 630 may further include dedicated electronics 634 and motion providers 636, such as miniature motors and motion transfer systems, as known. Alternatively, the motion may be transferred via the cable 620.

Figures 35B and 35C schematically illustrate side and distal views, respectively, of the radioactive-emission measuring probe 600, for the esophagus, having an ultrasound imager 640 at its distal tip 633. The ultrasound imager 640 may provide a structural image which may be correlated with the functional image. Additionally, it may be used for providing the size and location of the relevant organ for modeling. Furthermore, it may be used for providing attenuation correction to the radioactive emission measurements.

Figures 35D and 35E schematically illustrate side and distal views, respectively, of the radioactive-emission measuring probe 600, for the esophagus, having an MRI imager 642 at its distal tip 633. The MRI imager 642 may provide a structural image which may be correlated with the functional image. Additionally, it may be used for providing the size and location of the relevant organ for modeling. Furthermore, it may be used for providing attenuation correction to the radioactive emission measurements.

Figures 35F - 35I schematically illustrate the radioactive-emission measuring probe 600, for the esophagus, having a block 90 at its distal tip 633. The block 90 at the distal tip is also adapted for oscillatory motion, but about the x-axis, as seen by an arrow 53. When combined with the rotational motion around the x-axis, it produces traces 55 in the shape of a star, in the body section 230, as seen in Figure 35K.

Figures 35L – 35Q schematically illustrates the radioactive-emission measuring probe 600, for the esophagus, having a block 90 at its distal tip 633, adapted for a deployed and a retracted position, and for oscillatory motion about the

x-axis, when deployed. The probe 600 further has the ultrasound imager 640 at its distal tip 633, as a ring, similarly having a deployed and a retracted position.

Figures 35N – 35P illustrate the block 90 deployed, and the ultrasound imager 640 retracted. In this manner, the ultrasound imager 640 does not obstruct the oscillatory motion of the block 90 at the distal tip 633.

Figure 35Q illustrates the block 90 retracted and the ultrasound imager deployed so the block 90 does not obstruct the view of the ultrasound imager. It will be appreciated that the ultrasound image is to be taken once, from the distal tip 633, while the radioactive-emission measurements are to be taken at a plurality of orientations, from the distal tip 633.

Figures 35R and 35S schematically illustrates the body section 230, showing an esophagus 650. The radioactive-emission measuring probe 600 for the esophagus (Figures 35A – 35Q), is adapted for oral insertion, through a mouth 652, and is further designed for identifying pathological features in a neck area 654, for example, as relating to the vocal cords, the thyroid glands, the submandibular glands. Additionally, it is designed for identifying pathological features in the trachea 656, the lungs 658, the heart 660, the breasts, the stomach 662, the pancreas 664, and the liver 666, as well as other relevant organs and glands, for example, the lymph glands.

The probe system of the present invention allows imaging of internal organs from a close proximity. Additionally, it is particularly advantageous for overweight people and for women with large breasts, for whom extracorporeal imaging, for example, extracorporeal cardiac imaging by nuclear emission measurements, is ineffective, because of losses in the tissue.

For cardiac imaging, the radiopharmaceuticals associated with the probe of Figures 35A – 35Q may be Myoview™(technetium Tc-99m tetrofosmin), a cardiac imaging agent, of GE Healthcare, GE Medical Systems, http://www.gehealthcare.com/contact/contact_details.html#diothers. Alternatively, it may be Cardiolite (Sestamibi radilabeled with TC99), of DuPont, http://www1.dupont.com/NASApp/dupontglobal/corp/index.jsp?page=/content/US/en_US/contactus.html. It will be appreciated that other agents may be used, as known, for other relevant organs, for example, for the detection of cancerous tissue or other pathologies.

Example 12

Referring further to the drawings, Figures 36A- 36C schematically illustrate the body section 230, as a heart, which includes the region of interest 200, associated with the organ 215, being the heart 215. The heart 215 includes an aorta 242, a left atrium 244 and a right atrium 246.

Figure 36B schematically illustrates a second, inner region of interest 200', associated with the aorta 242.

Similarly, Figure 36C schematically illustrates a second, inner region of interest 200', associated with the left atrium 244.

Referring further to the drawings, Figures 37A – 52E schematically illustrate a cardiac probe system 500, in accordance with a preferred embodiment of the present invention.

Figures 37A – 37D schematically illustrate the basic components of the cardiac probe system 500, in accordance with the present invention. These include an operator computer station 510, a chair 520, and a radioactive-emission-measuring probe assembly 530.

As seen in Figure 37D, computer station 510 may be further adapted for input of an ultrasound imager 535, for example, a handheld ultrasound imager 535, possibly with a position-tracking device 537, or a 3-D ultrasound imager. The data provided by the ultrasound imager 535 may be used in the modeling of the heart. Preferably, the data of the ultrasound imager may be co-registered with the radioactive emission measurements, on the same frame of reference, for providing co-registration of structural and functional imaging. It will be appreciated that the imager 535 may be an MRI imager.

Figure 38 schematically illustrates the chair 520 and the probe assembly 530, arranged for operation, in accordance with a preferred embodiment of the present invention. Preferably, the chair 520 is in a partial reclining position, and the probe assembly 530 is designed to come against it, opposite the chest of a person, when sitting on the chair 520. Preferably, the probe assembly 530 includes a housing, which is substantially transparent to radioactive emission. Alternatively, no housing, or a housing which is open on the side facing a patient may be used.

It will be appreciated that another chair or a bed may be used rather than the chair 520. Alternatively, the patient may be standing.

Figures 39A – 39B schematically illustrate possible inner structures of the probe assembly, in accordance with preferred embodiments of the present invention.

Figure 39A schematically illustrates the inner structure of the probe assembly 530, showing the housing 20, the parallel lines of assemblies 92, possibly of an even number, each with a dedicated motion provider 76 and a dedicated secondary motion provider 78, and the rows of blocks 90, possibly arranged in pairs, along the assemblies 92.

The probe assembly 530 defines an internal frame of reference 80, while each assembly 92 has a reference cylindrical coordinate system of x;r, with rotation around x denoted by ω and rotation around r denoted by ϕ, wherein the oscillatory motion about r is denoted by the arrow 50.

Preferably, the motion of the probe assembly 530 corresponds to that described hereinabove, in conjunction with Figures 20A – 20H and 22A – 22H, as follows:

The plurality of blocks 90 is adapted for the windshield-wiper like oscillatory motion, around the radius r, as denoted by the arrow 50. The oscillatory motions may be synchronized in an antipodal manner, so as to be diametrically opposed to each other, as shown hereinabove in Figures 20B and 20E, by the arrows 54, and as shown hereinabove in Figures 20C and 20F by the arrows 56. However, other motions are also possible. For example, the blocks 90 may move together, or independently. It will be appreciated that an odd number of blocks 90 is also possible.

Furthermore, the plurality of assemblies 92 are preferably arranged in parallel, and their rotational motions, around the x-axis, in the direction of ω, may also be synchronized in an antipodal manner, so as to be diametrically opposed to each other, as shown hereinabove, in Figures 22C, by arrows 62, and as shown hereinabove in Figure 22G, by arrows 64. However, other motions are also possible. For example, the assemblies 92 may move together, or independently. It will be appreciated that an odd number of assemblies 92 is also possible.

Thus, the resultant traces are a large plurality of the broken line traces 59, as seen hereinabove, in conjunction with Figures 22D and 22H, on the chest of the patient.

In accordance with the present example,

i. The different blocks 90 provide views from different orientations;

ii. The different blocks 90 may change their view orientations;

iii. The different assemblies 92 provide views from different orientations; and

iv. The different assemblies 92 may change their view orientations.

The operational manner of the probe 530 is described hereinbelow in conjunction with Figure 23D, for the at least two assemblies 92.

Preferably, the motions of the blocks 90 and of the assemblies 92 are contained within the housing 20, so that the external surface of the probe assembly 530 remains stationary, wherein the external surface of the probe assembly 530 is substantially transparent to nuclear radiation. Alternatively, the housing may be open on the side facing the patient.

It will be appreciated that the oscillatory motions need not be synchronized in an antipodal manner. Rather, the blocks 90 may move together, or independently. It will be appreciated that an odd number of blocks 90 is also possible.

It will be appreciated that probe 530 may include a plurality of assemblies 92, which are not parallel to each other. For example, the assemblies 92 may be at right angles to each other, or at some other angle. It will be appreciated that the assemblies 92 may include detecting units 12 rather then blocks 90, for example, as in the probe 10 of Figures 20A – 20G.

Figure 39B schematically illustrates a section 531 of the probe assembly 530, showing the inner structure thereof, in accordance with another embodiment of the present invention. Accordingly, the probe assembly 530 may include the housing 20, and a single one of the assemblies 92, within the housing 20, having the dedicated motion provider 76, the dedicated secondary motion provider 78, and the rows of blocks 90. Additionally, in accordance with the present embodiment, the probe assembly 530 includes a tertiary motion provider 77, for sliding the assembly 90 laterally, in the directions of the arrow 75, along the chest of the patient (not shown). In this manner, imaging of the chest may be performed with the single assembly 92.

Figures 40A and 40B schematically illustrate the assembly 92 and the block 90, in accordance with a preferred embodiment of the present invention. In essence, the assembly 92 is constructed in a manner similar to the probe 10 of Figures 20A – 20H, and specifically Figure 20H, and according to Figure 23D, hereinabove.

Thus the assembly 92 includes a row of at least two blocks 90, each adapted of oscillatory motion about r. The blocks 90 are arranged within the inner housing 21.

A motor 88 and a shaft 85 form the motion provider 76, while a secondary motor 86 and a secondary shaft 84 form the secondary motion provider 78, for the oscillatory motion about r. A plurality of motion transfer systems 74, for example gear systems, equal in number to the number of blocks 90, transfer the motion of the secondary motion provider 78 to the blocks 90. The motion transfer systems 74, of gears, make it possible to provide the row of blocks 90 with any one of parallel oscillatory motion, antipodal oscillatory motion, or independent motion, depending on the gear systems associated with each block 90. It will be appreciated that other motion transfer systems, as known, may be used.

It will be appreciated that detecting units 12 may be used in place of blocks 90.

In accordance with the present example, adjacent blocks 90A and 90B may move in an antipodal manner and adjacent blocks 90C and 90D may move in an antipodal manner, while adjacent blocks 90B and 90C may move in parallel. It will be appreciated that many other arrangements are similarly possible. For example, all the pairing combinations of the blocks 90 may move in an antipodal manner, all the blocks 90 may move in parallel, or the blocks 90 may move independently. It will be appreciated that an odd number of blocks 90 may be used in the assembly 92.

Figure 50 schematically illustrates the block 90, in accordance with a preferred embodiment of the present invention. The block 90 includes a frame 93, which houses the detector material 91, which is preferably pixilated, and the collimators 96. Additionally, the frame 93 houses dedicated electronics 97, preferably on a PCB board 99. Furthermore, where several modules of the detector material 91 need to be used, a structural element 89 may be provided to hold the different modules of the detector material 91 together. It will be appreciated that a single pixel detector may be used. Alternatively, a single module of a pixilated detector may be used. Alternatively, the block 90 may be constructed as any of the examples taught in conjunction with Figures 17A – 17L, or as another block, as known.

The dimensions, which are provided in Figure 50, are in mm. It will be appreciated that other dimensions, which may be larger or smaller, may similarly be used.

FIG. 51 schematically illustrates the cardiac model 250, in accordance with a preferred embodiment of the present invention. The cardiac model 250 includes the volume U, for example, as a cylinder, and the anatomical constraints AC. The rows

of blocks 90 are arranged around the volume U, as permissible by the anatomical constraints AC.

FIGs. 52A – 52E schematically illustrate the blocks 90, arranged for viewing the cardiac model 250, in accordance with a preferred embodiment of the present invention.

In Figure 52A, the block 90 is shown with the frame 93, which houses the detector material 91, which is preferably pixilated, and the collimators 96. Additionally, the frame 93 houses the dedicated electronics 97, on the PCB board 99.

In Figure 52B, fields of view 98 of the blocks 90 are seen for a situation wherein adjacent blocks 90A and 90B move in an antipodal manner, while adjacent blocks 90B and 90C move in a nearly parallel manner. The figure illustrates that when moving in an antipodal manner, the blocks 90 do not obstruct each other's field of view 98. Yet, when moving in a parallel manner, or a near parallel manner, obstruction may occur.

A similar observation is made by Figure 52C, wherein the adjacent blocks 90B and 90C move in an antipodal manner, while the adjacent blocks 90A and 90B move in a near parallel manner.

Again, it will be appreciated that many other arrangements are similarly possible. For example, all the pairing combinations of the blocks 90 may move in an antipodal manner, all the blocks 90 may move in parallel, or the blocks 90 may move independently. It will be appreciated that an odd number of blocks 90 may be used in the assembly 92.

Figure 52D illustrates possible dimensions for the cardiac model 250. The dimensions are in mm. It will be appreciated that other dimensions are similarly possible. Furthermore, It will be appreciated that the model 250 may be based on general medical information of the organ 215 and common pathological features associated with it. Additionally, the model may be based on information related to a specific patient, such as age, sex, weight, and body type. Furthermore, a structural image, such as by ultrasound or MRI, may be used for providing information about the size and location of the heart 215 in relation to the body section 230 (Figure 5A), for generating the model 250.

Figure 52E schematically illustrates a possible arrangement of the blocks 90 for viewing the volume U of the model 250, within the anatomical constrains AC.

The significance of the present invention, as illustrated by Figures and 52E is that all the blocks maintain a close proximity to the modeled volume U, and to the region of interest, in vivo, even as they move. This is in sharp contrast to the prior art, for example, as taught by US Patent 6,597,940, to Bishop, et al, and US Patent 6,671,541, to Bishop, in which the blocks are fixed within a rigid housing, so that as some of the blocks are placed in close proximity to the body, others are forced away from the body, and their counting efficiency deteriorates.

Preferably, the radiopharmaceuticals associated with the probe of Figures 37A – 52E may be Myoview™(technetium Tc-99m tetrofosmin), a cardiac imaging agent, of GE Healthcare, GE Medical Systems, http://www.gehealthcare.com/contact/contact_details.html#diothers. Alternatively, it may be Cardiolite (Sestamibi radilabeled with TC99), of DuPont, http://www1.dupont.com/NASApp/dupontglobal/corp/index.jsp?page=/content/US/en_US/contactus.html. It will be appreciated that other agents may be used.

It will be appreciated that cardiac imaging, in accordance with the present invention relates to the imaging of the whole heart, or to a portion of the heart, or to blood vessels near the heart, for example, the coronary artery.

EXAMPLE 13

Referring further to the drawings, Figure 53 schematically illustrates a dual imaging system 700 for radioactive-emission-measurements in tandem with a three-dimensional structural imager, in accordance with a preferred embodiment of the present invention.

The dual imaging system 700 includes a three-dimensional structural imager 720, preferably, on a structural-imager gantry 722, and a radioactive-emission measuring probe 730, preferably, on a probe gantry 732. A patient 750 may lie on a bed 740, which is adapted for motion into the radioactive-emission measuring probe 730 and the three-dimensional structural imager 720, on a bed gantry 742.

A control unit 710 controls the operation of the dual system 700, including the three-dimensional structural imager 720, the radioactive-emission measuring probe 730, and the bed 740. The control unit 710 may also analyze the data.

Alternatively, two control units may be used, one for controlling the three-dimensional structural imager 720 and another for controlling the radioactive-

emission measuring probe 730. It will be appreciated that the control system of the radioactive-emission measuring probe 730 generally controls the order of the operation of the dual system 700, wherein the radioactive-emission measuring may be performed before or after the structural imaging.

It will be further appreciated that the radioactive-emission measuring probe 730 may be configured as an add-on system, adapted for operating with an existing structural imager. It may be supplied with a dedicated software, for example, in a CD format, or with its own control unit, which is preferably adapted for communication with the structural imager control unit.

The three-dimensional structural imager 720 may be, for example, a CT or an MRI, which defines a frame of reference, wherein the radioactive-emission measuring probe 730 is co-registered to the frame of reference.

In this manner, co-registration of functional and structural images is possible. Additionally, the structural image may be used for providing tissue information for attenuation correction of the functional image, resulting in a more accurate functional image.

The radioactive-emission measuring probe 730 may be constructed as one arc 730A, preferably adapted for viewing a full width of a body from a single position of the probe 730. Alternatively, the radioactive-emission measuring probe 730 may be constructed as two arcs 730A and 730B, which are adapted for viewing a full circumference of a body, from a single position of the probe 730. It will be appreciated that the probe 730 may have other geometries, for example, a circle, an ellipse, a polygon, a plurality of arcs forming a circle, or a plurality of sections, forming a polygon, or other shapes.

Preferably, where the probe 730 is adapted for viewing a full circumference of a patient, from a single position, the bed 740 is formed as a stretcher, with a sheet 744, which is substantially transparent to radioactive emission, for example, of a hydrocarbon material.

Figure 54 schematically illustrates a cross-sectional view of dual imaging system 700 for radioactive-emission-measurements in tandem with a three-dimensional structural imager, in accordance with a preferred embodiment of the present invention.

Preferably, the gantry 732 of the probe 730 is adapted for vertical motion, as described by the arrows 734, so as to bring the probe 730 closer to the patient 750.

Additionally, the gantry 722 of the three-dimensional structural imager 720 may be adapted for rotation, as described by an arrow 724.

The bed 740 is preferably adapted for motion into and out of the probe 730 and the three-dimensional structural imager 720.

Preferably, the rate of imaging by the three-dimensional structural imager 720 and by the radioactive-emission measuring probe is substantially the same, to the bed moves into the two imagers at a constant speed.

It will be appreciated that the body structure that may be imaged may be an organ, such as a heart or a pancreas, a gland, such as a thyroid gland or a lymph gland, blood vessels, for example, the coronary artery or the pulmonary artery, a portion of an organ, such as an aorta or a left atrium of a heart, a bone, a ligament, a joint, a section of the body, such as a chest or an abdomen, or a whole body.

Preferably, the radiopharmaceuticals associated with the probe of the present invention be any one of the following:

1. anti-CEA, a monoclonal antibody fragment, which targets CEA – produced and shed by colorectal carcinoma cells – and may be labeled by Tc^{99m} or by other radioisotopes, for example, iodine isotopes (Jessup JM, 1998, Tumor markers – prognostic and therapeutic implications for colorectal carcinoma, Surgical Oncology; 7: 139-151);

2. In^{111}-Satumomab Pendetide (Oncoscint®), designed to target TAG-72, a mucin-like glycoprotein, expressed in human colorectal, gastric, ovarian, breast and lung cancers, but rarely in healthy human adult tissues (Molinolo A; Simpson JF; et al., 1990, Enhanced tumor binding using immunohistochemical analyses by second generation anti-tumor-associated glycoprotein 72 monoclonal antibodies versus monoclonal antibody B72.3 in human tissue, Cancer Res., 50(4): 1291-8);

3. Lipid-Associated Sialic Acid (LASA), a tumor antigen, used for colorectal carcinoma, with a similar sensitivity as anti-CEA monoclonal antibody fragment but a greater specificity for differentiating between benign and malignant lesions (Ebril KM, Jones JD, Klee GG, 1985, Use and limitations of serum total and lipid-bound sialic acid concentrations as markers for colorectal cancer, Cancer; 55:404-409);

4. Matrix Metaloproteinase-7 (MMP-7), a proteins enzyme, believed to be involved in tumor invasion and metastasis (Mori M, Barnard GF et al., 1995, Overexpression of matrix metalloproteinase-7 mRNA in human colon carcinoma, Cancer; 75: 1516-1519);

5. Ga^{67} citrate, used for detection of chronic inflammation (Mettler FA, and Guiberteau MJ, Eds., 1998, Inflammation and infection imaging, Essentials of nuclear medicine, Fourth edition, Pgs: 387-403);

6. Nonspecific-polyclonal immunoglobulin G (IgG), which may be labeled with both In^{111} or Tc^{99m}, and which has a potential to localize nonbacterial infections (Mettler FA, and Guiberteau MJ, ibid);

7. Radio-labeled leukocytes, such as such as In^{111} oxine leukocytes and Tc^{99m} HMPAO leukocytes, which are attracted to sites of inflammation, where they are activated by local chemotactic factors and pass through the endothelium into the soft tissue (Mettler FA, and Guiberteau MJ, ibid; Corstens FH; van der Meer JW, 1999, Nuclear medicine's role in infection and inflammation, Lancet; 354 (9180): 765-70); and

8. Tc^{99m} bound to Sodium Pertechnetate, which is picked up by red blood cells, and may be used for identifying blood vessels and vital organs, such as the liver and the kidneys, in order to guide a surgical instrument without their penetration.

It will be appreciated that other agents may be used.

Figures 55A – 55C schematically illustrate possible inner structures of the probe 730, in accordance with preferred embodiments of the present invention.

Figure 55A schematically illustrates the inner structure of the probe 730, showing the housing 20 and the parallel lines of the assemblies 92, possibly of an even number, each with the row of blocks 90, possibly arranged in pairs. Each of the assemblies 92 preferably includes the dedicated motion provider 76, for providing the rotational motion around x, and the dedicated secondary motion provider 78, for providing the oscillatory motion about r in the direction of the arrow 50.

The probe 730 defines an internal frame of reference 80, while each assembly 92 has a reference cylindrical coordinate system of x;r, with rotation around x denoted by ω and rotation around r denoted by ϕ, wherein the oscillatory motion about r is denoted by the arrow 50.

Preferably, the motions of the assemblies 92 and the blocks 90 correspond to those described hereinabove, in conjunction with Figures 20A – 20H and 22A – 22H, as follows:

The plurality of blocks 90 is adapted for the windshield-wiper like oscillatory motion, around the radius r, as denoted by the arrow 50. The oscillatory motions may be synchronized in an antipodal manner, so as to be diametrically opposed to each other, as shown hereinabove in Figures 20B and 20E, by the arrows 54, and as shown hereinabove in Figures 20C and 20F by the arrows 56. However, other motions are also possible. For example, the blocks 90 may move together, or independently. It will be appreciated that an odd number of blocks 90 is also possible.

Furthermore, the plurality of assemblies 92 are preferably arranged in parallel, and their rotational motions, around the x-axis, in the direction of ω, may also be synchronized in an antipodal manner, so as to be diametrically opposed to each other, as shown hereinabove, in Figures 22C, by arrows 62, and as shown hereinabove in Figure 22G, by arrows 64. However, other motions are also possible. For example, the assemblies 92 may move together, or independently. It will be appreciated that an odd number of assemblies 92 is also possible.

Thus, the resultant traces are a large plurality of the broken line traces 59, as seen hereinabove, in conjunction with Figures 22D and 22H, on the skin of the patient.

In accordance with the present example,

i. The different blocks 90 provide views from different orientations;

ii. The different blocks 90 change their view orientations;

iii. The different assemblies 92 provide views from different orientations; and

iv. The different assemblies 92 change their view orientations.

The operational manner of the probe 730 is described hereinbelow in conjunction with Figure 23D, for the at least two assemblies 92.

Preferably, the motions of the blocks 90 and of the assemblies 92 are contained within the housing 20, so that the housing 20 of the probe 730 remains stationary, wherein the external surface of the probe 730 is substantially transparent to nuclear radiation. Alternatively, the housing may be open on the side facing the patient.

It will be appreciated that the oscillatory motions need not be synchronized in an antipodal manner. Rather, the blocks 90 may move together, or independently. It will be appreciated that an odd number of blocks 90 is also possible.

It will be appreciated that the probe 730 may include a plurality of assemblies 92, which are not parallel to each other. For example, the assemblies 92 may be at right angles to each other, or at some other angle. It will be appreciated that the assemblies 92 may include detecting units 12 rather then blocks 90, for example, as in the probe 10 of Figures 20A – 20G.

Figure 55B schematically illustrates a section 731 of the probe 730, showing the inner structure thereof, in accordance with another embodiment of the present invention. Accordingly, the probe 730 may include the housing 20, and a single one of the assemblies 92, within the housing 20, having the dedicated motion provider 76, the dedicated secondary motion provider 78, and the rows of blocks 90. Additionally, in accordance with the present embodiment, the probe 730 includes a tertiary motion provider 77, for sliding the assembly 90 laterally, in the directions of an arrow 75.

Figure 55C schematically illustrates an alternative arrangement of the blocks 90 around the volume U of the model 250, wherein each of the blocks 90 is provided with motion around the x axis, in the direction of ω, and with the oscillatory motion about r, preferably in the y-z plane, as illustrated by the arrow 50. Accordingly, the assemblies 92 need not be used. Rather, each of the blocks 90 may communicate with two motion providers which provide it with the two types of motion.

Figures 56A and 56B schematically illustrate the assembly 92 and the block 90, in accordance with a preferred embodiment of the present invention. In essence, the assembly 92 is constructed in a manner similar to the probe 10 of Figures 20A – 20H, and specifically Figure 20H, and according to Figure 23D, hereinabove.

Thus the assembly 92 includes a row of at least two blocks 90, each adapted of oscillatory motion about r. The blocks 90 are arranged within the inner housing 21.

A motor 88 and a shaft 85 form the motion provider 76, while a secondary motor 86 and a secondary shaft 84 form the secondary motion provider 78, for the oscillatory motion about r. A plurality of motion transfer systems 74, for example gear systems, equal in number to the number of blocks 90, transfer the motion of the secondary motion provider 78 to the blocks 90. The motion transfer systems 74, of gears, make it possible to provide the row of blocks 90 with any one of parallel oscillatory motion, antipodal oscillatory motion, or independent motion, depending on the gear systems associated with each block 90. It will be appreciated that other motion transfer systems, as known, may be used.

It will be appreciated that detecting units 12 may be used in place of blocks 90.

In accordance with the present example, adjacent blocks 90A and 90B may move in an antipodal manner and adjacent blocks 90C and 90D may move in an antipodal manner, while adjacent blocks 90B and 90C may move in parallel. It will be appreciated that many other arrangements are similarly possible. For example, all the pairing combinations of the blocks 90 may move in an antipodal manner, all the blocks 90 may move in parallel, or the blocks 90 may move independently. It will be appreciated that an odd number of blocks 90 may be used in the assembly 92.

It will be appreciated that many other probes and probe systems may be considered and the examples here are provided merely to illustrate the many types of combinations that may be examined, in choosing and scoring a probe design, both in terms of information and in terms of secondary considerations, such as rate of data collection, cost, and complexity of the design.

Example 14

Brain cancer is the leading cause of cancer-related death in patients younger than age 35, and in the United States, the annual incidence of brain cancer generally is 15–20 cases per 100,000 people.

There are two types of brain tumors: primary brain tumors that originate in the brain and metastatic (secondary) brain tumors that originate from cancer cells that have migrated from other parts of the body.

Approximately 17,000 people in the United States are diagnosed with primary cancer each year; nearly 13,000 die of the disease. Amongst children, the annual incidence of primary brain cancer is about 3 per 100,000.

Primary Brain Tumors are generally named according to the type of cells or the part of the brain in which they begin. The most common are gliomas, which begin in glial cells, and of which there are several types, as follows:

Astrocytoma, a tumor which arises from star-shaped glial cells called astrocytes, and which in adults, most often arises in the cerebrum, whereas in children, it occurs in the brain stem, the cerebrum, and the cerebellum.

Brain stem glioma, a tumor that occurs in the lowest part of the brain, and is diagnosed in young children as well as in middle-aged adults.

Ependymoma, a tumor, most common in middle-aged adults, which arises from cells that line the ventricles or the central canal of the spinal cord and which occurs in children and young adults.

Oligodendroglioma, a rare tumor, which arises from cells that make the fatty substance that covers and protects nerves and usually occurs in the cerebrum, grows slowly and generally does not spread into surrounding brain tissue.

Some types of brain tumors do not begin in glial cells. The most common of these are:

Medulloblastoma, also called a primitive neuroectodermal tumor, a tumor which usually arises in the cerebellum and is the most common brain tumor in children.

Meningioma, which arises in the meninges and usually grows slowly.

Schwannoma, also called an acoustic neuroma, and occurring most often in adults, it is a tumor that arises from a Schwann cell, of the cells that line the nerve that controls balance and hearing, in the inner ear.

Craniopharyngioma, a tumor which grows at the base of the brain, near the pituitary gland, and most often occurs in children.

Germ cell tumor of the brain, a tumor which arises from a germ cell, generally, in people younger than 30, the most common type of which is a germinoma.

Pineal region tumor, a rare brain tumor, which arises in or near the pineal gland, located between the cerebrum and the cerebellum.

Certain inherited diseases are associated with brain tumors, for example, Multiple endocrine neoplasia type 1 (pituitary adenoma), Neurofibromatosis type 2 (brain and spinal cord tumors), Retinoblastoma (malignant retinal glioma), Tuberous sclerosis (primary brain tumors), and Von Hippel-Lindau disease (retinal tumor, CNS tumors). Furthermore, genetic mutations and deletions of tumor suppressor genes (i.e., genes that suppress the development of malignant cells) increase the risk for some types of brain cancer.

Additionally, exposure to vinyl chloride is an environmental risk factor for brain cancer. Vinyl chloride is a carcinogen, used in the manufacturing of plastic products such as pipes, wire coatings, furniture, car parts, and house wares, and is present in tobacco smoke. Manufacturing and chemical plants may release vinyl

chloride into the air or water, and it may leak into the environment as a result of improper disposal. People who work in these plants or live in close proximity to them have an increased risk for brain cancer.

Secondary brain cancer occurs in 20–30% of patients with metastatic disease and its incidence increases with age. In the United States, about 100,000 cases of secondary brain cancer are diagnosed each year. Patients with a history of melanoma, lung, breast, colon, or kidney cancer are at risk for secondary brain cancer.

Brain tumors can obstruct the flow of cerebrospinal fluid (CSF), which results in the accumulation of CSF (hydrocephalus) and increased intracranial pressure (IICP). Nausea, vomiting, and headaches are common symptoms. They can damage vital neurological pathways and invade and compress brain tissue. Symptoms usually develop over time and their characteristics depend on the location and size of the tumor.

The first step in diagnosing brain cancer involves evaluating symptoms and taking a medical history. If there is any indication that there may be a brain tumor, various tests are done to confirm the diagnosis, including a complete neurological examination, imaging tests, and biopsy.

Referring now to the drawings, Figures 57A – 57F present the principles of modeling, for obtaining an optimal set of views, for a body organ 215, in accordance with the present invention.

Figure 57A schematically illustrates a body section 230, illustrating the organ 215, being the brain 215. The brain 215 is enclosed within a skull 830 and includes:

a cerebellum 802, which is the part of the brain below the back of the cerebrum. it regulates balance, posture, movement, and muscle coordination;

a corpus callosum 804, which is a large bundle of nerve fibers that connect the left and right cerebral hemispheres;

a frontal lobe of the cerebrum 806, which is the top, front regions of each of the cerebral hemispheres, and is used for reasoning, emotions, judgment, and voluntary movement;

a medulla oblongata 808, which is the lowest section of the brainstem (at the top end of the spinal cord) and controls automatic functions including heartbeat, breathing, and the like;

a occipital lobe of the cerebrum 810, which is the region at the back of each cerebral hemisphere, at the back of the head, and contains the centers of vision and reading ability;

a parietal lobe of the cerebrum 812, which is the middle lobe of each cerebral hemisphere between the frontal and occipital lobes, located at the upper rear of the head, and which contains important sensory centers;

a pituitary gland 814, which is a gland attached to the base of the brain that secretes hormones, and is located between the pons and the corpus callosum;

pons 816, which is the part of the brainstem that joins the hemispheres of the cerebellum and connects the cerebrum with the cerebellum, located just above the medulla oblongata;

a spinal cord 818, which is a thick bundle of nerve fibers that runs from the base of the brain to the hip area, through the spine (vertebrae);

a temporal lobe of the cerebrum 820, which is the region at the lower side of each cerebral hemisphere, located at the sides of the head and containing centers of hearing and memory.

The brain 215 may include a pathological feature 213, termed herein an organ target 213. A region of interest (ROI) 200 may be defined so as to encompass the brain 215 and the pathological feature 213.

As seen in Figure 57B, the region of interest 200 of Figure 57A is modeled as a model 250 of a volume U, and the organ target 213 is modeled as a modeled organ targets HS. Additionally, there are certain physical viewing constraints, associated with the region of interest 200, which are modeled as anatomical constraints AC. In the present case, the skull 830 creates viewing constraints, and generally, imaging the brain is performed extracorporeally.

Referring further to the drawings, Figure 58 pictorially illustrates a method 340 for zooming in on a suspected pathological feature, as a process of two or more iterations, in accordance with the present invention, as follows:

As seen in Figure 58, the method 340 may be described, pictorially, as follows:

In I: The region of interest 200, associated with the organ 215, such as the brain 215, is defined for the body section 230.

In II: The model 250 of the volume U is provided for the region of interest 200, possibly with one or several of the modeled organ targets HS, and within the anatomical constraints AC, for obtaining the optimal set of views for the region of interest 200. The optimal set of views is then applied to the region of interest 200, encompassing the brain 215 of the body section 230.

In III: When the suspected organ target 213 is identified, in vivo, in the brain 215, by radioactive-emission measurements at the optimal set of views, a second, inner region of interest 200' is defined, encircling the suspected pathological feature. For example, if a suspected pathology 213 is identified in the occipital lobe 810 of the cerebrum, that is, the region at the back of each cerebral hemisphere at the back of the head, the second region of interest 200' is defined so as to encircle the occipital lobe 810 of the cerebrum.

In IV: A model 250' of a volume U' is provided for the second, inner region of interest 200', preferably, with at least one modeled organ target HS, simulating the suspected organ target 213, for obtaining an optimal pathology set of views for the region of interest 200'. The second, pathology set of views is then applied to the second, inner region of interest 200' of the body section 230. In the present example, the second, pathology set of views is then applied to the occipital lobe 810 of the cerebrum, in vivo.

Referring further to the drawings, Figures 59A – 60H schematically illustrate a probe system 850 for the brain, in accordance with a preferred embodiment of the present invention.

Figures 59A – 59C schematically illustrate the radioactive-emission-measuring probe for the brain, in accordance with the present invention;

Preferably, radioactive-emission-measuring probe 850 for the brain is shaped as a helmet 860, adapted for wearing on a head 862. The helmet 860 is preferably mounted on a gantry 870, which may be adjustable in the directions of arrows 872, 874 and 876, for adapting to individual heights and comfort.

Alternatively, no gantry is used, and the helmet 860 may be worn directly on the head 862, for example, like a motorcycle helmet.

A chair 880 may be provided for the comfort of the patient.

Preferably, the radioactive-emission-measuring probe 850 for the brain is operable with a control unit 890, which may be a desktop computer, a laptop, or the

like. The control unit 890 is preferably used both for controlling the motions of the detecting units 12, blocks 90 and assemblies 92 of the radioactive-emission-measuring probe 850 for the brain and for analyzing the data.

It will be appreciated that the radioactive-emission-measuring probe 850 for the brain may be supplied merely as the probe helmet 860 and a data storage device, such as a CD 892, a disk 892, or the like, containing the appropriate software, for operation with an existing computer, at the site.

It will be appreciated that the radioactive-emission-measuring probe 850 for the brain may be operable with a structural imager, as taught by commonly owned PCT publication WO2004/042546, whose disclosure is incorporated herein by reference. The structural imager may be a handheld ultrasound imager, possibly with a position-tracking device, a 3-D imager such as an ultrasound imager, a CT imager, or an MRI imager, as known. The data provided by the structural imager may be used for any one or a combination of the following:

i. obtaining accurate dimensional data for modeling the brain 215, as taught in conjunction with Figures 57A - 58 and 11 - 12;

ii. providing attenuation correction for the radioactive-emission-measurements, based on the structural data, as taught by commonly owned PCT publication WO2004/042546; and

iii. co-registering the functional and structural images, as taught, for example, by commonly owned PCT publication WO2004/042546.

Referring further to the drawings Figures 60A – 60K schematically illustrate inner structures of the probe 850 in accordance with several embodiments of the present invention.

Figure 60A schematically illustrates the assembly 92, comprising, for example four of the blocks 90, adapted for oscillatory motion about the r-axis, as illustrated by the arrows 50, and adapted for rotational motion about the x-axis, as illustrated by the arrow 62, as taught, for example, in conjunction with Figures 22A – 22H. It will be appreciated that detecting units 12 may be used in place of blocks 90.

Figure 60B schematically illustrates a possible cross sectional view of the probe 850 (Figure 59C), showing an arrangement of the assemblies 92, laterally around the head 862.

Figure 60C schematically illustrates a top view of the probe 850, showing an arrangement of the assemblies 92, laterally around the head 862. It will be appreciated that the number of the blocks 90 may vary around the head 862.

Figures 60D and 60E schematically illustrate other possible cross sectional views of the probe 850, showing arrangements of the assemblies 92, vertically around the head 862.

Figure 60F schematically illustrates the probe 850 formed as the helmet 860, with the assemblies 92, arranged as illustrated by the cross sectional view of Figure 60E. It will be appreciated that other arrangements are similarly possible. Preferably, the probe helmet 860 includes a housing 864. Preferably, the motions of the blocks 90 and of the assemblies 92 are contained within the housing 864.

Preferably, the proximal side of the housing 864 with respect to the head 862 (Figure 59C) is transparent to nuclear radiation. Alternatively, the proximal side with respect to the head 862 is open.

Figure 60G schematically illustrates another arrangement of the blocks 90 around the head 862, wherein the blocks 90 are not arranged in assemblies 92; rather each block 90 moves as an individual body. It will be appreciated that the detecting units 12 may be used in place of the blocks 90.

Figures 60H – 60K schematically illustrate possible rotational motions of the blocks 90, each of the blocks 90 moving as an individual body for obtaining views of different orientations. As seen in Figure 60H, the block 90 rotates around x as seen by an arrow 852 and at each position around x, oscillates about x, as seen by an arrow 851. The resultant traces are seen in Figure 60I as a star of line traces 854.

Alternatively, as seen in Figure 60J, the block 90 rotates around y as seen by an arrow 853 and at each position around y, oscillates about x, as seen by the arrow 851. The resultant traces are seen in Figure 60K, as line traces 855.

The assembly 92 and the block 90, in accordance with a preferred embodiment of the present invention are described in Figures 40A and 40B, hereinabove.

Thus the assembly 92 includes a row of at least two blocks 90, each adapted of oscillatory motion about r. The blocks 90 are arranged within the inner housing 21.

A motor 88 and a shaft 85 form the motion provider 76, while a secondary motor 86 and a secondary shaft 84 form the secondary motion provider 78, for the oscillatory motion about r. A plurality of motion transfer systems 74, for example

gear systems, equal in number to the number of blocks 90, transfer the motion of the secondary motion provider 78 to the blocks 90. The motion transfer systems 74, of gears, make it possible to provide the row of blocks 90 with any one of parallel oscillatory motion, antipodal oscillatory motion, or independent motion, depending on the gear systems associated with each block 90. It will be appreciated that other motion transfer systems, as known, may be used.

It will be appreciated that detecting units 12 may be used in place of blocks 90.

In accordance with the present example, adjacent blocks 90A and 90B may move in an antipodal manner and adjacent blocks 90C and 90D may move in an antipodal manner, while adjacent blocks 90B and 90C may move in parallel. It will be appreciated that many other arrangements are similarly possible. For example, all the pairing combinations of the blocks 90 may move in an antipodal manner, all the blocks 90 may move in parallel, or the blocks 90 may move independently. It will be appreciated that an odd number of blocks 90 may be used in the assembly 92.

It will be appreciated that imaging, in accordance with the present invention relates to the imaging of the whole brain, or to a portion of the brain, or to blood vessels near the brain, for example, the coronary artery.

Preferably, the radiopharmaceuticals associated with the probe of the present invention may be Tc99m-d, l-hexamethyl propylene amine oxime (1-HMPAO) commercially known as Ceretec by GE-Amersham, or ^{99m}Tc-ECD, commercially known as Neurolite, and made by Bristol Myers Squibb.

The present invention applies to the two types of brain tumors: primary brain tumors, which originate in the brain and metastatic (secondary) brain tumors that originate from cancer cells that have migrated from other parts of the body.

Additionally, the primary brain tumors may be gliomas, which begin in glial cells, and of which there are several types, as follows:

Astrocytoma, a tumor which arises from star-shaped glial cells called astrocytes, and which in adults, most often arises in the cerebrum, whereas in children, it occurs in the brain stem, the cerebrum, and the cerebellum.

Brain stem glioma, a tumor that occurs in the lowest part of the brain, and is diagnosed in young children as well as in middle-aged adults.

Ependymoma, a tumor, most common in middle-aged adults, which arises from cells that line the ventricles or the central canal of the spinal cord and which occurs in children and young adults.

Oligodendroglioma, a rare tumor, which arises from cells that make the fatty substance that covers and protects nerves and usually occurs in the cerebrum, grows slowly and generally does not spread into surrounding brain tissue.

Additionally or alternatively, the present invention applies to other types of brain tumors, which do not begin in glial cells. The most common of these are:

Medulloblastoma, also called a primitive neuroectodermal tumor, a tumor which usually arises in the cerebellum and is the most common brain tumor in children.

Meningioma, which arises in the meninges and usually grows slowly.

Schwannoma, also called an acoustic neuroma, and occurring most often in adults, it is a tumor that arises from a Schwann cell, of the cells that line the nerve that controls balance and hearing, in the inner ear.

Craniopharyngioma, a tumor which grows at the base of the brain, near the pituitary gland, and most often occurs in children.

Germ cell tumor of the brain, a tumor which arises from a germ cell, generally, in people younger than 30, the most common type of which is a germinoma.

Pineal region tumor, a rare brain tumor, which arises in or near the pineal gland, located between the cerebrum and the cerebellum.

Additionally or alternatively, the present invention applies to tumors associated with certain inherited diseases, for example, Multiple endocrine neoplasia type 1 (pituitary adenoma), Neurofibromatosis type 2 (brain and spinal cord tumors), Retinoblastoma (malignant retinal glioma), Tuberous sclerosis (primary brain tumors), and Von Hippel-Lindau disease (retinal tumor, CNS tumors), and genetic mutations and deletions of tumor suppressor genes (i.e., genes that suppress the development of malignant cells), which increase the risk for some types of brain cancer.

Additionally or alternatively, the present invention applies to tumors associated with exposure to vinyl chloride.

Additionally or alternatively, the present invention applies to secondary brain cancer, for example, originating from the lungs, the breasts, or other parts of the body.

It will be appreciated that the present invention further applies to other types brain tumors, which may be malignant or benign, blood clots in the brain, and other brain pathologies. It will be appreciated that many other probes and probe systems may be considered and the examples here are provided merely to illustrate the many types of combinations that may be examined, in choosing and scoring a probe design, both in terms of information and in terms of secondary considerations, such as rate of data collection, cost, and complexity of the design.

Example 15

This is illustrated hereinbelow, in conjunction with Figures 61A – 61B and 12.

Referring further to the drawings, Figure 61A pictorially illustrates a method 340 for zooming in on a suspected pathological feature, as a process of two or more iterations, in accordance with the present invention, as follows:

As seen in Figure 61A, the method 340 may be described, pictorially, as follows:

In I: The region of interest 200, associated with the organ 215, such as the breast 215, is defined for the body section 230.

In II: The model 250 of the volume U is provided for the region of interest 200, possibly with one or several of the modeled organ targets HS, and within the anatomical constraints AC, for obtaining the optimal set of views for the region of interest 200. The optimal set of views is then applied to the region of interest 200, encompassing the breast 215 of the body section 230.

In III: When the suspected organ target 213 is identified, in vivo, in the breast 215, by radioactive-emission measurements at the optimal set of views, a second, inner region of interest 200' is defined, encircling the suspected pathological feature.

In IV: A second model 250' of a second volume U' is provided for the second, inner region of interest 200', preferably, with at least one modeled organ target HS, simulating the suspected organ target 213, for obtaining an optimal pathology set of views for the second region of interest 200'. The second, pathology set

of views is then applied to the second, inner region of interest 200' of the body section 230.

Alternatively, as seen in Figure 61B, the method 340 may be described, pictorially, as follows:

In I: The region of interest 200, associated with the organ 215, such as the breast 215, is defined for the body section 230, when compressed between two plates 902 and 904, for example, mammograph plates.

In II: The model 250 of the volume U is provided for the region of interest 200, possibly with one or several of the modeled organ targets HS, and within the anatomical constraints AC, representing the mammograph plates, for obtaining the optimal set of views for the region of interest 200. The optimal set of views is then applied to the region of interest 200, encompassing the breast 215 of the body section 230.

In III: When the suspected organ target 213 is identified, in vivo, in the breast 215, by radioactive-emission measurements at the optimal set of views, a second, inner region of interest 200' is defined, encircling the suspected organ target 213.

In IV: A second model 250' of a second volume U' is provided for the second, inner region of interest 200', preferably, with at least one modeled organ target HS, simulating the suspected organ target 213, for obtaining an optimal pathology set of views for the second region of interest 200'. The second, pathology set of views is then applied to the second, inner region of interest 200' of the body section 230.

Figures 61A – 61B schematically illustrate the modeling of a breast in accordance with the present invention. However, generally the breast is tested when compressed, as described hereinbelow.

Mammography is currently the most effective method of screening for breast cancer, for the detection of early non-palpable tumors. In essence, it involves compressing the breast between two plates, a support plate and a compression plate, and passing x-rays through the compressed breast. The compression is desirous both in order to spread the breast fatty tissue thin, to reduce its attenuation, and in order to fix the breast tissue, with respect to a frame of reference, so that the x-ray image may be correlated with a surgical tool frame of reference, such as a biopsy needle frame of

reference, for guiding the surgical tool to a suspected location on the x-ray image, without the breast tissue moving between the taking of the x-ray image and the guiding of the surgical tool.

Often stereotactic mammography is applied, meaning that the x-ray head is rotated with respect to the plates, so as to provide at least two views of the fixed breast, compressed between the plates, from at least two angles, for stereo imaging.

In general, each breast is imaged separately, generally, both in a vertical direction and from the side (laterally), preferably, stereotactically. In other words, generally, at least four views of each breast are taken, two vertically and two laterally.

A surgical instrument, for example, a biopsy needle, or an ablation device, such as a cryosurgery device, an ultrasound ablation device, a knife, or a laser ablation device, may be built onto the mammograph, its frame of reference correlated with that of the x-ray image.

Figure 62A schematically illustrates the basic mammograph 900, showing a structural support 929, which defines a frame of reference 80, and which includes a support plate 902 and a compression plate 904, the compression plate 904 being adapted for motion along an arrow 906, so as to compress a breast 909 on the support plate 902.

An x-ray tube 905 is preferably arranged so as to move within a track 907, for obtaining x-ray images of the compressed breast 909 from at least two views, so as to obtain stereotactic viewing, for depth evaluation. A film 901 is preferably arranged under the breast 909, for example, under the support plate 902, for registering the x-ray image.

Additionally, the mammograph 900 is preferably adapted for rotation, as illustrated by an arrow 908, for compressing a breast from at least two orientations, for example vertically and laterally.

A surgical tool 903, for example, a biopsy needle 903 or an ablation device 903, such as by cryosurgery or laser, or a knife 903, may be built onto the mammograph 900, its frame of reference correlated with the frame of reference 80, using position tracking devices or a linkage system, as known.

Figures 62B and 62C schematically illustrate a system 925 of an ultrasound imager 915, operative with the two plates 902 and 904, in accordance with the present invention. The importance of performing ultrasound between two plates, as in the

case of x-rays, is that the two plates fix the breast with respect to the frame of reference 80, and in fact, convert the breast to a rigid-like tissue, so that any suspicious findings can be located by the surgical tool 903.

In Figure 62B, the ultrasound imager 915 is arranged to slide along tracks 917, for example, on the compression plate 904, while a layer of gel 913 or hydrogel 913, between the compression plate 904 and the breast 909 ensures good contact for ultrasound imaging. In this manner, an ultrasound image, correlated to the frame of reference 80, when the breast is under compression, may be obtained.

Alternatively, as seen in Figure 62C the ultrasound imager 915 may be built onto the structural support 929, its frame of reference correlated with the frame of reference 80, using position tracking devices or a linkage system, as known.

Referring further to the drawings, Figures 63A – 63E schematically illustrate a radioactive-emission-measuring probe 1000 for the breast, for operation with the mammograph 900 of Figure 62A, or for operation with another system, wherein a breast is compressed between two plates, in accordance with the present invention.

Figure 63A schematically illustrates an external appearance of the radioactive-emission-measuring probe 1000, for the breast. The probe 1000 has a driving portion 990 and an imaging portion 980, enclosed in a sheath 985. The imaging portion 980 defines cylindrical coordinates 987 of a longitudinal axis along the x-axis, and an r-axis, perpendicular to the longitudinal axis.

Figures 63B – 63C schematically illustrate an internal structure of the radioactive-emission-measuring probe 1000, for the breast. The imaging portion 980 includes several of the blocks 90, for example, between two and six of the blocks 90, arranged within the sheath 985. It will be appreciated that another number, which may be larger or smaller, and which may be odd or even, may be employed.

In Figure 63C, the motions experienced by the blocks 90 are illustrated with respect to the cylindrical coordinates 987 of x;r.

A first motion is a rotational motion of all the blocks 90, moving as a single body, with the shaft 85 and the internal housing 21, around the x-axis, in the direction between + ω and - ω, as illustrated by the arrow 52. The first motion is powered by the motor 88.

A second motion is an oscillatory motion of the individual blocks 90, powered by the secondary motor 86, the secondary shaft 84, and the motion transfer link 74,

the motion transfer link 74 moving in a linear, sliding motion, as shown by the arrow 71.

At each orientation of the internal housing 21 with respect to ω, around x, the second, oscillatory motion about r takes place, individually by each of the block 90, the oscillatory motion about r being between $-\phi$ and $+\phi$, as illustrated by the arrow 50, and as taught hereinabove, in conjunction with Figure 21A - 21H.

Thus, the overall motion is as illustrated hereinabove, in conjunction with Figure 16D and Figures 21A - 21H.

Further as seen in Figure 63C, the rotational motion in the direction of the arrow 52 is provided by a motor 88 and the shaft 85, which together form the motion provider 76. The motor 88 may be an electric motor, for example, a servo motor. The oscillatory motion in the direction of the arrow 50 is provided by a secondary motor 86, a secondary shaft 84 and a motion transfer link 74. The secondary motor 86 may also be an electric motor, for example, a servo motor. The secondary motor 86, secondary shaft 84 and the motion transfer link 74, together, form the secondary motion provider 78, for the oscillatory motion, in the direction of the arrow 50.

Thus, for the radioactive-emission-measuring probe 1000, for the breast:

i. The different blocks 90 provide views from different orientations; and

ii. The different blocks 90 may change their view orientations independent of each other.

It is important to point out that during the operation of the probe 1000, the sheath 985 of the imaging portion 980 (Figures 63A and 63B) remains stationary, while the internal housing 21 (Figure 63C) rotates around the x axis. The sheath 985 may be formed of a carbon fiber, a plastic, or another material, which is substantially transparent to nuclear radiation.

Figures 63D and 63E illustrate further the oscillatory motion of the blocks 90, within the sheath 985, as described by the arrows 50, by showing the blocks 90 at different positions, along their oscillatory travel. Figures 63D and 63E further illustrate a viewing side 986 and a back side 988 for the probe 1000.

Referring further to the drawings, Figures 64A – 64M schematically illustrate systems 910, which include the radioactive-emission-measuring probes 1000 for the breast, operating with systems, in which a breast is compressed between two plates, for example, as in the mammograph 900, in accordance with the present invention.

Preferably, as seen in Figures 64A and 64B, the probes 1000 are mounted onto the two plates, the compression plate 904, and the support plate 902, such that their viewing sides 986 face each other. Preferably, the probes 1000 are aligned with the x axis, as seen. Alternatively, the probes 1000 may be aligned with the y axis. It will be appreciated that the probes 1000 may be mounted only on one plate, the compression plate 904 or the support plate 902.

Additionally, as seen in Figure 64C, one or several of the probes 1000 may be mounted as edge probes, for positioning at edges 992 and 994, supplementing the probes 1000 mounted on the plates, for obtaining views from the sides of the compressed breast.

An alternative embodiment is illustrated in Figure 64D, wherein a single one of the probes 1000 may be mounted on each of the plates 902 and 904, the probe 1000 being adapted for travel along a track 914, in a direction of an arrow 918, by a dedicated motion provider 916, thus providing the views that a plurality of the probes 1000 would have provided, as illustrated in Figures 64A – 64B.

It will be appreciated that edge probes 1000, may be added to the embodiment of Figure 64D, in a manner similar to that of Figure 64C.

Figure 64E schematically illustrates a control unit 890, for controlling the motions of the blocks 90 or the detecting units 12 (Figures 20A – 22D) of the probes 1000 and for analyzing the measurements and constructing the images. Preferably, a single control unit is used both for the x-ray imager, or the ultrasound imager 915, on the one hand, and the radioactive-emission-measuring probes 1000, on the other. Alternatively, individual control units may be used, one for each modality. Alternatively, the system 910 for the breast is provided with a storage device 892, such as a CD or a disk, which contains the software for operating the system 910 for the breast with an existing computer on the site. It will be appreciated that the control unit 890 may be a PC, a laptop, a palmtop, a computer station operating with a network, or any other computer as known.

In accordance with the present invention, frames may be provided for mounting the radioactive-emission-measuring probes 1000 on the plates 902 and 904.

As seen in Figure 64F, a frame 912 may be provided for either the support plate 902 or the compression plate 904, designed for accepting the probes 1000 lengthwise, by inserting the probes 1000 in holes 926.

Alternatively, as seen in Figure 64G, the frame 912 may be designed for accepting the probes 1000 widthwise.

Additionally, as seen in Figure 64H, a frame 922 is designed for accepting the probes 1000 widthwise or lengthwise, wherein the frame 922 further includes an edge section 924, for supporting the edge probes of Figure 64C.

Furthermore, as seen in Figure 64I, two complementary frames may be provided, one designed as the frame 922, for accepting the probes 1000 lengthwise (or widthwise) along the plate and for accepting the edge probes, as illustrated in Figure 64H, and the other, designed as the frame 912, for accepting the probes 1000 lengthwise (or widthwise) along the plate.

As seen in Figure 64J, a frame 923 may be designed for accepting a single one of the probes 1000, lengthwise, adapted for sliding widthwise along the plate, in a channel 928, by the dedicated motion provider 916. Alternatively, the frame 923 may be designed for accepting the probe 1000 widthwise, adapted for sliding lengthwise.

As seen in Figure 64K, a frame 927 may be designed for accepting a single one of the probes 1000, for example, lengthwise, adapted for sliding widthwise along the plate, in a channel 928, by the dedicated motion provider 916, wherein the frame 927 further includes the edge section 924, for supporting the edge probe 1000 of Figure 64C.

In accordance with the present invention, nuclear imaging by radioactive-emission-measurements, co-registered with x-ray mammography, may be obtained by a method 1010, illustrated in Figure 64L, in a flowchart form, as follows:

in a box 1012: the breast is compressed between the plates;

in a box 1014: an x-ray mammography is performed, as seen in Figure 62A, preferably from at least two orientations of the x-ray tube 905;

in a box 1016: the probes 1000 are mounted on the plates, and radioactive-emission measurements are performed;

in a box 1018: where necessary, the surgical tool 903 may be employed, while the breast is still compressed between the two plates.

It will be appreciated that the steps of boxes 1014 and 1016 may be performed in any order.

Preferably, the images of the x-ray mammography and the nuclear imaging are co-registered and analyzed together.

However, it will be appreciated that only nuclear imaging by radioactive-emission measurements may be performed, without x-ray imaging.

Where ultrasound imaging co-registered with nuclear imaging by radioactive-emission-measurements is desired, a method 1020, illustrated in Figure 64M, in flowchart form, applies, as follows:

in a box 1022: a hydrogel layer is placed between one of the plates, for example, the compression plate 904 and the breast, or a gel is spread over the breast, so as to serve as an ultrasound interface between the plate and the breast;

in a box 1024: the breast is compressed between the plates;

in a box 1026: the probes 1000 are mounted on the plates, and radioactive-emission measurements are performed;

in a box 1028: the probes 1000 are replaced by an ultrasound imager, for example as illustrated in Figures 62B or 62C, and ultrasound imaging is performed;

in a box 1030: where necessary, the surgical tool 903 may be employed, while the breast is still compressed between the two plates.

It will be appreciated that the steps 1026 and 1028 may be performed in any order.

Preferably, the images of the x-ray mammography and the nuclear imaging are co-registered and analyzed together.

Referring further to the drawings, Figures 65A – 65C schematically illustrate a radioactive-emission-measuring probe 930, for imaging a breast under vacuum, in accordance with another preferred embodiment of the present invention.

As seen in Figure 65A, the probe 930 includes a vacuum cup 934, shaped as a cone and connected to a vacuum system 932, for creating a vacuum in a cavity 935 within. The vacuum in the cavity is used both to stretch the breast so as to spread the fatty tissue thin and to fix the breast tissue with respect to a frame of reference, so a

surgical device may be employed, where needed, while the breast tissue remains fixed in place.

A vacuum ring 936, for example of natural or synthetic rubber, helps maintain the vacuum in the cup 934.

The vacuum cup 934 defines the frame of reference 80 and a plurality of the blocks 90 are arranged along the walls 938 of the suction cup 934, each adapted for at least one, and preferably two rotational motions, for example, as illustrated in conjunction with Figures 25A – 25E and Figures 25I – 25J, or Figures 25F – 25H, for imaging a breast in the cavity 935. Alternatively, the blocks 90 may be arranged in the assemblies 92, as illustrated in conjunction with Figures 24A – 24H.

A surgical tool may be attached to the probe 930, and correlated to its frame of reference, for example as taught in conjunction with Figure 62B.

The motions of the blocks 90 are preferably automatic, controlled by the control unit 890 (Figure 64C).

Preferably, the inner walls 938 of the cup 934 are substantially transparent to radioactive emission.

Figure 65B schematically illustrates an embodiment wherein a vacuum cylinder 934 is used in place of a conical cup, and the blocks 90 are arranged in assemblies 92, for example, as illustrated in conjunction with Figures 16E and 24A – 24H.

Figure 65C schematically illustrates an embodiment wherein the vacuum cylinder 934 is used, and a single one of the assemblies 92 is arranged for traveling around the cylinder 934, in the direction of an arrow 940, by a motion provider 942.

Referring further to the drawings, Figures 66A – 66F schematically illustrate a radioactive-emission-measuring probe 950, for imaging the breasts in the natural state, in accordance with another preferred embodiment of the present invention.

As seen in Figure 66A, the radioactive-emission-measuring probe 950, for imaging the breasts in a natural state, is designed as an extracorporeal unit which may be positioned against the breasts, operating as taught in conjunction with any one of Figures 20A – 25J. Preferably, the radioactive-emission-measuring probe 950, for imaging the breasts is attached to a gantry 952, which may provide adjustments as seen by arrows 954 and 956.

Additionally, the patient may be positioned on a chair 960, as seen in figure 66B.

The control unit 890 may be used for controlling the motions of the blocks 90 (Figures 24A – 24H or 25A – 25J) or the detecting units 12 (Figures 20A – 20G, or Figures 22A – 22D) and for analyzing the measurements and constructing the images. Alternatively, the radioactive-emission-measuring probe 910 for the breast is supplied with a storage device 892, which contains the software for operating the radioactive-emission-measuring probe 910 for the breast with an existing computer on the site. It will be appreciated that the control unit 890 may be a PC, a laptop, a palmtop, a computer station operating with a network, or any other computer as known.

Figure 66D schematically illustrates a woman 970 being examined by the radioactive-emission-measuring probe 950, when seated on the chair 960. It will be appreciated that the examination may also be conducted when the woman 970 is standing or lying on a bed.

Figure 66E schematically illustrates the inner structure radioactive-emission-measuring probe 950 in accordance with a preferred embodiment of the present invention. Figure 66E shows the housing 20, the parallel lines of assemblies 92, possibly of an even number, each with a dedicated motion provider 76 and a dedicated secondary motion provider 78, and the rows of blocks 90, possibly arranged in pairs, along the assemblies 92.

The probe 950 defines the frame of reference 80, while each assembly 92 has a reference cylindrical coordinate system of x;r, with rotation around x denoted by the arrow 62 and oscillatory motion about r, denoted by the arrow 50.

Figure 66F schematically illustrates the model 250 of the two breasts, modeled as the volumes U, and the anatomical constraints associated with them, for determining an optimal set of views for radioactive-emission measurements.

It will be appreciated that imaging, in accordance with the present invention relates to the imaging of the whole breast, or to a portion of the breast, the armpits near the breasts, (and) or the two breasts.

Preferably, the radiopharmaceuticals associated with the radioactive-emission-measuring probe for the breast may be Tc^{99m} bound to Sestamibi, a small protein molecule, made for example, by Bristol Myers Squibb, and marketed as Miraluma, used widely for breast cancer detection.

The present invention applies to detecting and differentiating between various types of breast disorders, for example as illustrated in Figure 1A, hereinabove, as follows.

i. fibroadenomas 8, which are fibrous, benign growths in breast tissue.

ii. cysts 9, which are fluid-filled sacs and may disappear sometimes by themselves, or a doctor may draw out the fluid with a needle.

iii. a breast abscess 11, which is a collection of pus, resulting from an infection.

iv. fibrocystic breast disease 13, which is a common condition characterized by an increase in the fibrous and glandular tissues in the breasts, resulting in small, nodular cysts, noncancerous lumpiness, and tenderness, wherein treatment of the cysts may be all that is needed.

v. a tumor 15, which may be precancerous or cancerous, and which usually shows up as a white area on a mammogram even before it can be felt. In cases where the tumor 15 is cancerous, it may appear as a white area with radiating arms. A cancerous tumor 15 may have no symptoms or may cause swelling, tenderness, discharge from the nipple 4, indentation of the nipple 4, or a dimpled appearance 17 in the skin over the tumor.

Additionally, the present invention applies to detecting various types of breast cancers, such as:

i. ductal cancer, which affects the cells of the ducts;

ii. lobular cancer, which begins in the lobes or lobules of the breast; and

iii. inflammatory breast cancer, which is an uncommon type of breast cancer and causes the breast to be warm, red, and swollen.

It will be appreciated that the present invention further applies to other types breast disorders, which may be cancerous, precancerous, or benign.

Additionally or alternatively, the present invention applies to secondary breast cancer, for example, originating from the lungs, or other parts of the body.

Furthermore, the radioactive-emission-measuring probe for the breast may be designed for and used on a single breast or designed for and used simultaneously on the two breasts.

It will be appreciated that although breast cancer in men and children is rare, the present invention may be used for the detection of breast cancer in men and children as well.

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It will be appreciated that many other probes and probe systems may be considered and the examples here are provided merely to illustrate the many types of combinations that may be examined, in choosing and scoring a probe design, both in terms of information and in terms of secondary considerations, such as rate of data collection, cost, and complexity of the design.

It will be appreciated that the methods of the present invention apply to pathological features that may be modeled as regions of concentrated radiations, or hot regions, regions of low-level radiation, which is nonetheless above background level, and regions of little radiation, or cold regions, below the background level. However, in general, for identifying a pathological feature of the heart, they relate to cold regions.

It will be appreciated that the methods of the present inventions may be operable by computer systems and stored as computer programs on computer-readable storage media.

It will be appreciated that the body may be an animal body or a human body.

It will be appreciated that the radioactive-emission-measuring systems, probes and methods of the present invention may be used with commonly owned US Applications 20040015075 and 20040054248 and commonly owned PCT publication WO2004/042546, all of whose disclosures are incorporated herein by reference. These describe systems and methods for scanning a radioactive-emission source with a radioactive-emission-measuring probe of a wide-aperture collimator, and at the same time, monitoring the position of the radioactive-emission-measuring probe, at very fine time intervals, to obtain the equivalence of fine-aperture collimation. In

consequence, high-efficiency, high-resolution, images of a radioactive-emission source are obtained.

Commonly owned US application 20040054248 and commonly owned PCT publication WO2004/042546 further disclose various extracorporeal and intracorporeal systems, of radioactive-emission-measuring probes, of relatively wide apertures, associated with position-tracking devices.

It will be appreciated that the radioactive-emission-measuring systems, probes and methods of the present invention may be used with commonly owned US Patent 6,173,201 to Front, whose disclosure is incorporated herein by reference, as well as by M. W. Vannier and D. E. Gayou, "Automated registration of multimodality images", Radiology, vol. 169 pp. 860-861 (1988); J. A. Correia, "Registration of nuclear medicine images, J. Nucl. Med., vol. 31 pp. 1227-1229 (1990); J-C Liehn, A. Loboguerrero, C. Perault and L. Demange, "superposition of computed tomography and single photon emission tomography immunoscinigraphic images in the pelvis: validation in patients with colorectal or ovarian carcinoma recurrence", Eur. J. Nucl. Med., vol. 19 pp. 186-194 (1992); F. Thomas et al., "Description of a prototype emission transmission computed tomography imaging system", J. Nucl. Med., vol. 33 pp. 1881-1887 (1992); D. A. Weber and M. Ivanovic, "Correlative image registration", Sem. Nucl. Med., vol. 24 pp. 311-323 (1994); and Hasegawa et al., U.S. Pat. No. 5,376,795.

These relate to the acquisition of both a functional image of the body, such as a radioactive-emission image, and a structural image, such as an ultrasound, an x-ray, or an MRI image, and their co-registration on a single frame of reference.

In essence, several images may be acquired and co-registered to the same frame of reference, as follows:

i. a first functional image scan, based for example, on anti-CEA monoclonal antibody fragment, labeled by iodine isotopes, may be acquired for targeting CEA - produced and shed by colorectal carcinoma cells for detecting a pathological feature, such as colorectal carcinoma;

ii. a second functional image, based for example, on nonspecific-polyclonal immunoglobulin G (IgG), which may be labeled with Tc^{99m}, may be acquired for locating blood vessels and vital structures, such as the heart, or the stomach, co-registered with the first functional image and the pathological feature detected on it,

in order to locate the pathological feature in reference to blood vessels and vital organs; and

iii. a structural image, such as an ultrasound image, may be used for general structural anatomy, co-registered with the first and second functional images, in order to locate the pathological feature in reference to bones and the general anatomic structure.

Thus, a physician may locate the pathological feature in reference to the blood vessels, vital organs, and the bones, and guide a minimally invasive surgical instrument to the pathological feature, while avoiding the blood vessels, vital organs, and bones. The minimally invasive surgical instrument may be a biopsy needle, a wire, for hot resection, a knife for cold resection, an instrument of focused energy, to produce ablation, for example, by ultrasound, or by laser, an instrument for cryosurgery, an instrument for croyetherapy, or an instrument for bractherapy, wherein seeds of a radioactive metal are planted close to a tumor, for operating as a radioactive source near the tumor.

Commonly owned PCT publication WO2004/042546 further discloses that the surgical instrument may be visible on at least one of the images, for example, on the structural image, to enable the physician to see the instrument, the pathological feature, and the surrounding anatomy on the display 129 (Figure 3A). Additionally, the surgical instrument may be radioactively labeled, to be visible also on the functional image. PCT publication WO2004/042546 further disclose various extracorporeal and intracorporeal systems, of radioactive-emission-measuring probes, and structural imagers such as an ultrasound probe or an MRI probe.

Commonly owned US Patent 6,173,201, to Front further discloses a method of stereotactic therapy, wherein a frame, which includes at least three markers, visible on a structural image, is rigidly secured to a patient. The structural image of a region inside the patient's body, which includes a pathological feature and the markers, is acquired. A functional image of the pathological feature is then acquired and co-registered with the structural image, to correlate the images to the same frame of reference. A stereotactic guide is rigidly attached to the frame and is used to guide a surgical instrument, such as a biopsy needle or a brachytherapy needle, to the pathological feature, with reference to the co-registered images.

Thus the radioactive-emission-measuring systems, probes and methods of the present invention may be used together with position tracking devices, for enhanced image acquisition, they may be used together with structural imager and structural imaging for correlating functional and structural images, and they may be used for guiding minimally invasive surgical instruments, such as a biopsy needle, a wire, for hot resection, a knife for cold resection, an instrument of focused energy, to produce ablation, for example, by ultrasound, or by laser, an instrument for cryosurgery, an instrument for croyetherapy, or an instrument for bractherapy.

It will be appreciated that a structural image, such as by ultrasound may further be used and in order to provide information about the size and location of the body structure 215 for the purpose of creating the model 250 (Figure 5A).

It will be appreciated that a structural image, such as by ultrasound may further be used and in order to provide information about tissue attenuation, for example, as taught in conjunction by commonly owned PCT publication WO2004/042546, whose disclosure is incorporated herein by reference. The information may then be used to correct the radioactive-emission measurements.

It is expected that during the life of this patent many relevant radioactive-emission-measuring systems, probes and methods will be developed and the scope of these terms is intended to include all such new technologies a priori.

As used herein the term “about” refers to ± 20 %.

It is appreciated that certain features of the invention, which are, for clarity, described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the invention, which are, for brevity, described in the context of a single embodiment, may also be provided separately or in any suitable subcombination.

Although the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, it is intended to embrace all such alternatives, modifications and variations that fall within the spirit and broad scope of the appended claims.

All publications, patents and patent applications mentioned in this specification are herein incorporated in their entirety by reference into the specification, to the same extent as if each individual publication, patent or patent application was specifically

and individually indicated to be incorporated herein by reference. In addition, any citation or identification of any reference in this application shall not be construed as an admission that such reference is available as prior art to the present invention.

What is claimed:

1. A method of radioactive-emission-measurement imaging, comprising:

providing a radioactive-emission-measuring probe, which includes at least one detecting unit, arranged within a housing and having a freedom of motion in at least one direction with respect to said housing, wherein at each position and orientation of said detecting unit, with respect to said housing, said detecting unit defines a view;

determining a probability that a photon emitted at a voxel, centered at an x;y;z position, in a volume, relative to said radioactive-emission-measuring probe, will be detected by said detecting unit, at a given view;

providing a first algorithm for choosing a plurality of views, for said detecting unit;

moving said detecting unit to positions associated with said plurality of views and obtaining radioactive-emission-measurements at said positions; and

providing a second algorithm for reconstructing a volumetric radiation distribution, within said volume, from said radioactive-emission-measurements at said positions.

2. The method of claim 1, and wherein said at least one detecting unit includes a plurality of detecting units.

3. The method of claim 1, and wherein said at least one detecting unit includes a plurality of detecting units, arranged in blocks, each block moving as a single body.

4. The method of claim 1, and wherein said freedom of motion in said at least one direction with respect to said housing includes at least one rotational motion with respect to said housing.

5. The method of claim 1, and wherein said freedom of motion in said at least one direction with respect to said housing includes at least two motions with respect to said housing.

6. A computer system, configured for:

a method of radioactive-emission-measurement imaging, which comprises:

providing a radioactive-emission-measuring probe, which includes at least one detecting unit, arranged within a housing and having a freedom of motion in at least one direction with respect to said housing, wherein at each position and orientation of said detecting unit, with respect to said housing, said detecting unit defines a view;

determining a probability that a photon emitted at a voxel, centered at an x;y;z position, in a volume, relative to said radioactive-emission-measuring probe, will be detected by said detecting unit, at a given view;

providing a first algorithm for choosing a plurality of views, for said detecting unit;

moving said detecting unit to positions associated with said plurality of views and obtaining radioactive-emission-measurements at said positions; and

providing a second algorithm for reconstructing a volumetric radiation distribution, within said volume, from said radioactive-emission-measurements at said positions.

7. A computer-readable storage medium containing a set of instructions for radioactive-emission-measurement imaging, comprising:

providing a radioactive-emission-measuring probe, which includes at least one detecting unit, arranged within a housing and having a freedom of motion in at least one direction with respect to said housing, wherein at each position and orientation of said detecting unit, with respect to said housing, said detecting unit defines a view;

determining a probability that a photon emitted at a voxel, centered at an x;y;z position, in a volume, relative to said radioactive-emission-measuring probe, will be detected by said detecting unit, at a given view;

providing a first algorithm for choosing a plurality of views, for said detecting unit;

moving said detecting unit to positions associated with said plurality of views and obtaining radioactive-emission-measurements at said positions; and

providing a second algorithm for reconstructing a volumetric radiation distribution, within said volume, from said radioactive-emission-measurements at said positions.

8. A method for predefining a set of radioactive-emission measurement views, for functional imaging, tailored to a specific body structure, and optimized with respect to the functional information gained about the body structure, comprising:

modeling the body-structure, based on its geometry;

modeling the anatomical constraints, which limit accessibility to the body structure;

obtaining a collection of views of the modeled body-structure, within the modeled anatomical constraints;

providing a scoring function, by which any set of at least one view, from the collection of views, is scorable with a score that rates the information obtained from the modeled body structure, by the set;

forming sets of views from the collection of views and scoring them, with the scoring function; and

selecting one of the sets of views, from the collection of views, based on its score, as the predefined set of views.

9. The method of claim 8, wherein the scoring function is based on an information theoretic measure of uniformity.

10. The method of claim 8, wherein the modeling the body-structure includes modeling a radiation emission density distribution to form at least one region of interest.

11. The method of claim 10, wherein the scoring function is based on an information theoretic measure of reliability.

12. The method of claim 11, wherein:

the modeling the body-structure comprises providing a plurality of models of substantially identical volumes, but different regions of interest.

the forming sets of views from the collection of views and scoring them, comprises forming substantially identical sets of views for all the models and scoring the sets with respect to each model, based on the information theoretic measure of reliability;

the selecting one of the sets of views, based on its score, comprises selecting based on the average score for the plurality of models.

13. The method of claim 10, wherein:

the modeling the body-structure comprises providing a pair of models of substantially identical volumes, but different regions of interest, wherein the difference between the regions of interest is defined by at least one delta;

the scoring function is based on an information theoretic measure of separability;

the forming the sets of views from the collection of views and scoring them, comprises forming substantially identical sets of views for the pair of models and scoring the sets with respect to the pair; and

the selecting one of the sets of views, based on its score, comprises selecting based on the score for the pair.

14. The method of claim 10, wherein:

the modeling the body-structure comprises providing a plurality of pairs of models of substantially identical volumes, but different regions of interest, wherein the difference between the regions of interest for each pair is defined by at least one delta;

the scoring function is based on an information theoretic measure of separability;

the forming the sets of views from the collection of views and scoring them, comprises forming substantially identical sets of views for the plurality of pairs of models and scoring the sets with respect to each of the pairs; and

the selecting one of the sets of views, based on its score, comprises selecting based on an average score for the plurality of pairs.

15. The method of claim 8, wherein:

the modeling the body-structure comprises providing at least one model of no radiation emission density distribution and at least two models of different radiation emission density distributions, so as to form different regions of interest for those two models; and

the providing the scoring function comprises providing a scoring function as a combination of uniformity, separability and reliability.

16. The method of claim 8, wherein the forming sets of views from the collection of views and scoring them, with the scoring function, includes using the Greedy construction.

17. The method of claim 8, wherein each view of the collection of views is determined for a given detecting unit, by at least one parameter selected from the group consisting of a location, an orientation, a pharmaceutical, a duration of measurement, and a time elapsed form the administration of the pharmaceutical.

18. The method of claim 8, wherein each view of the collection of views is determined at least by one detecting-unit parameter selected from the group consisting of a detector's material, a detector's thickness, a collimator's collection angle, and a diameter of the detecting unit.

19. The method of claim 8, wherein the obtaining the collection of views comprises computing the group of probabilities which form each view, analytically.

20. The method of claim 8, wherein the obtaining the collection of views comprises obtaining the group of probabilities which form each view, by computer simulations, based on the model of the body structure and the view parameters.

21. The method of claim 8, wherein the obtaining the collection of views comprises obtaining the group of probabilities which form each view, by measurements of a substantially point source from different locations and orientations, by a detecting unit.

22. The method of claim 8, wherein the obtaining the collection of views comprises obtaining the group of probabilities which form each view, by measurements of a physical model of the body structure, embedded with an emission source, from different locations and orientations, by a detecting unit.

23. The method of claim 8, wherein the body structure is selected from the group consisting of a prostate, a heart, a brain, a breast, a uterus, an ovary, a liver, a kidney, a stomach, a colon, a small intestine, an oral cavity, a throat, a gland, a lymph node, the skin, another body organ, a limb, a bone, another part of the body, and a whole body.

24. The method of claim 8, wherein the body structure is selected from the group consisting of a human body structure and an animal body structure.

25. The method of claim 8, wherein the modeling the body-structure comprises modeling based on at least one factor selected from the group consisting of age, sex, weight and body type.

26. A computer system, configured for:

a method for predefining a set of radioactive-emission measurement views, for functional imaging, tailored to a specific body structure, and optimized with respect to the functional information gained about the body structure, comprising:

modeling the body-structure, based on its geometry;

modeling the anatomical constraints, which limit accessibility to the body structure;

obtaining a collection of views of the modeled body-structure, within the modeled anatomical constraints;

providing a scoring function, by which any set of at least one view, from the collection of views, is scorable with a score that rates the information obtained from the modeled body structure, by the set;

forming sets of views from the collection of views and scoring them, with the scoring function; and

selecting one of the sets of views, from the collection of views, based on its score, as the predefined set of views.

27. A computer-readable storage medium containing a set of instructions for predefining a set of radioactive-emission measurement views, for functional imaging, tailored to a specific body structure, and optimized with respect to the functional information gained about the body structure, comprising:

modeling the body-structure, based on its geometry;

modeling the anatomical constraints, which limit accessibility to the body structure;

obtaining a collection of views of the modeled body-structure, within the modeled anatomical constraints;

providing a scoring function, by which any set of at least one view, from the collection of views, is scorable with a score that rates the information obtained from the modeled body structure, by the set;

forming sets of views from the collection of views and scoring them, with the scoring function; and

selecting one of the sets of views, from the collection of views, based on its score, as the predefined set of views.

28. A method of functional imaging, tailored to a specific body structure, and optimized with respect to the functional information gained about the body structure, comprising:

modeling the body-structure, based on its geometry;

modeling anatomical constraints, which limit accessibility to the body structure;

obtaining a collection of views of the modeled body-structure, within the modeled anatomical constraints;

providing a scoring function, by which any set of at least one view, from the collection of views is scorable with a score that rates information obtained from the modeled body structure, by the set;

forming sets of views from the collection of views and scoring them, with the scoring function;

selecting one of the sets of views from the collection of views, based on its score, as a predefined set of views; and

performing diagnostic radioactive-emission measurements of an in-vivo body structure that corresponds to the body structure that has been modeled, selectively at the predefined set of views.

29. A computer system, configured for:

a method of functional imaging, tailored to a specific body structure, and optimized with respect to the functional information gained about the body structure, comprising:

modeling the body-structure, based on its geometry;

modeling anatomical constraints, which limit accessibility to the body structure;

obtaining a collection of views of the modeled body-structure, within the modeled anatomical constraints;

providing a scoring function, by which any set of at least one view, from the collection of views is scorable with a score that rates information obtained from the modeled body structure, by the set;

forming sets of views from the collection of views and scoring them, with the scoring function;

selecting one of the sets of views from the collection of views, based on its score, as a predefined set of views; and

performing diagnostic radioactive-emission measurements of an in-vivo body structure that corresponds to the body structure that has been modeled, selectively at the predefined set of views.

30. A computer-readable storage medium containing a set of instructions for functional imaging, tailored to a specific body structure, and optimized with respect to the functional information gained about the body structure, comprising:

modeling the body-structure, based on its geometry;

modeling anatomical constraints, which limit accessibility to the body structure;

obtaining a collection of views of the modeled body-structure, within the modeled anatomical constraints;

providing a scoring function, by which any set of at least one view, from the collection of views is scorable with a score that rates information obtained from the modeled body structure, by the set;

forming sets of views from the collection of views and scoring them, with the scoring function;

selecting one of the sets of views from the collection of views, based on its score, as a predefined set of views; and

performing diagnostic radioactive-emission measurements of an in-vivo body structure that corresponds to the body structure that has been modeled, selectively at the predefined set of views.

31. A method of zooming in on a location of suspected pathology within a body structure, during diagnostic radioactive-emission measurements, in vivo, comprising:

modeling the body-structure, based on its geometry;

modeling anatomical constraints, which limit accessibility to the body structure;

obtaining a first collection of views of the modeled body-structure, within the modeled anatomical constraints;

providing a first scoring function, by which any set of at least one view, from any collection of views is scorable with a score that rates information obtained from the modeled body structure by the set;

forming sets of views from the first collection of views and scoring them, with the first scoring function;

selecting one of the sets of views from the first collection of views, based on its score, as the predefined set of views;

performing diagnostic radioactive-emission measurements of an in-vivo body structure that corresponds to the body structure that has been modeled, selectively at the predefined set of views;

identifying the location of suspected pathology;

modeling the suspected pathology within the modeled body-structure;

modeling anatomical constraints, which limit accessibility to the suspected pathology within the body-structure;

obtaining a second collection of views of the modeled suspected pathology within the modeled body-structure and the modeled anatomical constraints;

providing a second scoring function;

forming sets of views from the second collection of views and scoring them, with the second scoring function;

selecting one of the sets of views from the second collection of views, based on its score, as a predefined pathology set of views; and

performing diagnostic radioactive-emission measurements of the in-vivo pathology, selectively at the predefined pathology set of views.

32. A method for identifying a probe design optimized with respect to functional information gained about a body structure, comprising:

modeling a body-structure, based on its geometry;

modeling anatomical constraints, which limit accessibility to the body structure;

obtaining representative collections of views of the modeled body-structure, within the modeled anatomical constraints, for different probe designs;

providing a scoring function, by which each representative collection of views, associated with a specific probe design, is scorable with a score that rates information, obtained from the body-structure;

scoring the representative collections of views of the different probe designs; and

selecting a probe design, based on the score of its representative collection of views.

33. A radioactive-emission-measuring-probe system comprising:

a housing;

at least one detecting unit, located within the housing and adapted for at least one form of motion with respect to the housing;

at least one motion provider, in mechanical communication with the at least one detecting unit, for providing it with the at least one form of motion;

a controller, in signal communication with the at least one motion provider, for instructing it regarding said at least one form of motion of the at least one detecting unit, thus automatically providing said at least one detecting unit with said at least one form of motion.

34. The radioactive-emission-measuring-probe system of claim 33, wherein the at least one detecting unit includes a plurality of detecting units, each detecting unit moving independently.

35. The radioactive-emission-measuring-probe system of claim 33, wherein the at least one detecting unit includes a plurality of assemblies of detecting units, each assembly moving as a single body, and each assembly moving independently.

36. The radioactive-emission-measuring-probe system of claim 33, wherein the at least one detecting unit includes a plurality of lines of detecting units, each line moving as a single body, and each line moving independently.

37. The radioactive-emission-measuring-probe system of claim 33, wherein the at least one detecting unit includes a plurality of lines of assemblies, each line moving as a single body, and each line moving independently.

38. The radioactive-emission-measuring-probe system of claim 33, wherein the at least one form of motion with respect to the housing includes at least two forms of motion with respect to the housing.

39. The radioactive-emission-measuring-probe system of claim 33, wherein the at least one motion provider includes at least two motion providers.

40. The radioactive-emission-measuring-probe system of claim 33, wherein the controller instructs the at least one motion provider of the at least one motion in accordance with predefined views, tailored to a specific body structure, and optimized with respect to information gained about the body structure, obtained by a method comprising:

modeling the body-structure, based on its geometry;

modeling the anatomical constraints, which limit accessibility to the body structure;

obtaining a collection of views of the modeled body-structure, within the modeled anatomical constraints;

providing a scoring function, by which any set of at least one view, from the collection of views, is scorable with a score that rates the information obtained from the modeled body structure, by the set;

forming sets of views from the collection of views and scoring them, with the scoring function; and

selecting one of the sets of views, from the collection of views, based on its score, as the predefined set of views.

41. A radioactive-emission-measuring-probe system, tailored to a prostate, comprising:

a housing;

at least one detecting unit, located within the housing and configured for at least one form of motion with respect to the housing, for performing radioactive-emission-measurements of the prostate at different views;

at least one motion provider, in mechanical communication with the at least one detecting unit, for providing it with the at least one form of motion, with respect to the housing;

a controller, in signal communication with the at least one motion provider, for instructing it regarding the at least one form of motion of the at least one detecting unit, thus automatically providing the at least one detecting unit with the at least one form of motion.

42. A radioactive-emission-measuring-probe system, tailored to a prostate, comprising:

a housing, which defines cylindrical coordinates of a longitudinal axis and a radius, the housing having an external surface which is substantially transparent to nuclear radiation;

an inner housing, located within the housing and aligned with the longitudinal axis;

at least two assemblies, located on the inner housing, each comprising a plurality of detecting units, and each moving as a single body, wherein each is configured for an oscillatory motion, about the radius, for performing radioactive-emission-measurements of the prostate at different views about the radius;

a motion provider, in mechanical communication with the inner housing, for providing a step-wise rotation to the inner housing with the at least two assemblies, around the longitudinal axis, for performing radioactive-emission-measurements of the prostate at different views about the longitudinal axis;

a secondary motion provider, in mechanical communication with the at least two assemblies, for providing each of the assemblies with the oscillatory motion, about the radius, wherein the oscillatory motion of each of the assembly, about the radius, is performed for each of the steps of the rotation around the longitudinal axis;

a controller, in signal communication with the motion provider and the secondary motion provider, for instructing them regarding the motions of the at least two assemblies and the inner housing thus providing the probe with automatic motion, and for registering the motions, so as to correlate each measurement with the corresponding location and orientation of the detecting unit that performed the measurement,

wherein the motions of the at least two assemblies and the inner housing are contained within the housing so that the outer surface of the probe remains stationary.

43. A method for predefining a set of radioactive-emission measurement views, for functional imaging, tailored to a prostate, and optimized with respect to the functional information gained about the prostate, comprising:

modeling the prostate, based on its geometry;

modeling the anatomical constraints, which limit accessibility to the prostate;

obtaining a collection of views of the modeled prostate, within the modeled anatomical constraints;

providing a scoring function, by which any set of at least one view, from the collection of views, is scorable with a score that rates the information obtained from the modeled prostate, by the set;

forming sets of views from the collection of views and scoring them, with the scoring function; and

selecting one of the sets of views, from the collection of views, based on its score, as the predefined set of views.

44. A method of functional imaging, tailored to a prostate, and optimized with respect to the functional information gained about the prostate, comprising:

modeling the prostate, based on its geometry;

modeling anatomical constraints, which limit accessibility to the prostate;

obtaining a collection of views of the modeled prostate, within the modeled anatomical constraints;

providing a scoring function, by which any set of at least one view, from the collection of views is scorable with a score that rates information obtained from the modeled prostate, by the set;

forming sets of views from the collection of views and scoring them, with the scoring function;

selecting one of the sets of views from the collection of views, based on its score, as a predefined set of views; and

performing diagnostic radioactive-emission measurements of an in-vivo prostate that corresponds to the prostate that has been modeled, selectively at the predefined set of views.

45. A method of zooming in on a location of a suspected pathology within a prostate, during diagnostic radioactive-emission measurements, in vivo, comprising:

modeling the prostate, based on its geometry;

modeling anatomical constraints, which limit accessibility to the prostate;

obtaining a first collection of views of the modeled prostate, within the modeled anatomical constraints;

providing a first scoring function, by which any set of at least one view, from any collection of views is scorable with a score that rates information obtained from the modeled prostate by the set;

forming sets of views from the first collection of views and scoring them, with the first scoring function;

selecting one of the sets of views from the first collection of views, based on its score, as the predefined set of views;

performing diagnostic radioactive-emission measurements of an in-vivo prostate that corresponds to the prostate that has been modeled, selectively at the predefined set of views;

identifying the location of the suspected pathology;

modeling the location of the suspected pathology within the modeled prostate;

modeling anatomical constraints, which limit accessibility to the location of the suspected pathology within the prostate;

obtaining a second collection of views of the modeled location of the suspected pathology within the modeled prostate and the modeled anatomical constraints;

providing a second scoring function;

forming sets of views from the second collection of views and scoring them, with the second scoring function;

selecting one of the sets of views from the second collection of views, based on its score, as a predefined pathology set of views; and

performing diagnostic radioactive-emission measurements of the in-vivo pathology, selectively at the predefined pathology set of views.

46. A method for identifying a probe design optimized with respect to functional information gained about a prostate, comprising:

modeling a prostate, based on its geometry;

modeling anatomical constraints, which limit accessibility to the prostate;

obtaining representative collections of views of the modeled prostate, within the modeled anatomical constraints, for different probe designs;

providing a scoring function, by which each representative collection of views, associated with a specific probe design, is scorable with a score that rates information, obtained from the prostate;

scoring the representative collections of views of the different probe designs; and

selecting a probe design, based on the score of its representative collection of views.

47. A radioactive-emission-measuring probe for imaging a body structure from a body lumen, the probe comprising:

a housing, which defines cylindrical coordinates of a longitudinal axis and a radius, the housing being substantially transparent to nuclear radiation;

at two detecting units, arranged in a row along the longitudinal axis, each adapted for individual oscillatory motion about the radius, for performing radioactive-emission-measurements at different views about the radius;

an inner housing, located within the housing and aligned with the longitudinal axis, adapted for rotational motion around the longitudinal axis, the at least two detecting units rotating with it, for performing radioactive-emission-measurements at different views about the longitudinal axis,

wherein the motions of the at least two detecting units and of the inner housing are contained within the housing, while the housing remains stationary.

48. A method for predefining a set of radioactive-emission measurement views, for functional imaging of a body structure of a woman's reproductive system, optimized with respect to the functional information gained about the body structure, comprising:

modeling the body structure, based on its geometry;

modeling the anatomical constraints, which limit accessibility to the body structure;

obtaining a collection of views of the modeled body structure, within the modeled anatomical constraints;

providing a scoring function, by which any set of at least one view, from the collection of views, is scorable with a score that rates the information obtained from the modeled body structure, by the set;

forming sets of views from the collection of views and scoring them, with the scoring function; and

selecting one of the sets of views, from the collection of views, based on its score, as the predefined set of radioactive-emission measurement views.

49. A method for functional imaging of a body structure of a woman's reproductive system, optimized with respect to the functional information gained about the body structure, comprising:

modeling the body structure, based on its geometry;

modeling anatomical constraints, which limit accessibility to the body structure;

obtaining a collection of views of the modeled body structure, within the modeled anatomical constraints;

providing a scoring function, by which any set of at least one view, from the collection of views is scorable with a score that rates information obtained from the modeled body structure, by the set;

forming sets of views from the collection of views and scoring them, with the scoring function;

selecting one of the sets of views from the collection of views, based on its score, as a predefined set of views; and

performing diagnostic radioactive-emission measurements of an in-vivo body structure that corresponds to the body structure that has been modeled, selectively at the predefined set of views.

50. A method of zooming in on a location of a suspected pathological feature within a body structure, relating to a woman's reproductive system, during diagnostic radioactive-emission measurements, in vivo, comprising:

modeling the body structure, based on its geometry;

modeling anatomical constraints, which limit accessibility to the body structure;

obtaining a first collection of views of the modeled body structure, within the modeled anatomical constraints;

providing a first scoring function, by which any set of at least one view, from any collection of views is scorable with a score that rates information obtained from the modeled body structure by the set;

forming sets of views from the first collection of views and scoring them, with the first scoring function;

selecting one of the sets of views from the first collection of views, based on its score, as a predefined set of views;

performing diagnostic radioactive-emission measurements of an in-vivo body structure that corresponds to the body structure that has been modeled, selectively at the predefined set of views;

identifying the suspected pathological feature;

modeling the suspected pathological feature within the modeled body structure;

modeling anatomical constraints, which limit accessibility to the suspected pathological feature within the body structure;

obtaining a second collection of views of the modeled location of the suspected pathological feature within the modeled body structure and the modeled anatomical constraints;

providing a second scoring function;

forming sets of views from the second collection of views and scoring them, with the second scoring function;

selecting one of the sets of views from the second collection of views, based on its score, as a predefined pathology set of views; and

performing diagnostic radioactive-emission measurements of the in-vivo suspected pathological feature, selectively at the predefined pathology set of views.

51. A method for identifying a radioactive-emission-measuring-probe design for imaging a body structure, relating to a woman's reproductive system, the design being optimized with respect to functional information gained about the body structure, the method comprising:

modeling the body structure, based on its geometry;

modeling anatomical constraints, which limit accessibility to the body structure;

obtaining representative collections of views of the modeled body structure, within the modeled anatomical constraints, for different probe designs;

providing a scoring function, by which each representative collection of views, associated with a specific probe design, is scorable with a score that rates information, obtained from the body structure;

scoring the representative collections of views of the different probe designs; and

selecting a probe design, based on the score of its representative collection of views.

52. A radioactive-emission-measuring probe for imaging a body structure from a body lumen, the probe comprising:

a housing, which defines cylindrical coordinates of a longitudinal axis and a radius, the housing being substantially transparent to nuclear radiation;

a detecting unit, adapted for individual oscillatory motion about the radius, for performing radioactive-emission-measurements at different views about the radius, and for rotational and translational motions about the longitudinal axis, for performing radioactive-emission-measurements at different views along the longitudinal axis and at different orientations thereof;

wherein the motions of the detecting unit are contained within the housing, which remains stationary.

53. A radioactive-emission-measuring-probe, for the esophagus, comprising:

an extracorporeal portion, which includes a control unit;

an intracorporeal portion comprising:

a housing, which defines cylindrical coordinates of a longitudinal axis and a radius, the housing having an external surface which is substantially transparent to nuclear radiation;

at least two detecting units, arranged in a row along the longitudinal axis, each adapted for individual oscillatory motion about the radius, for performing radioactive-emission-measurements at different views about the radius;

an inner housing, located within the housing and aligned with the longitudinal axis, adapted for rotational motion around the longitudinal axis, the at least two detecting units rotating with it,

wherein the motions of the at least two detecting units and of the inner housing are contained within the housing so that the outer surface of the radioactive-emission-measuring-probe remains stationary,

and wherein a flexible cable connects the extracorporeal portion with the intracorporeal portion.

54. The radioactive-emission-measuring probe of claim 53, wherein the at least two detecting units move independently of each other.

55. A method for predefining a set of radioactive-emission measurement views, for functional imaging from the esophagus, optimized with respect to the functional information gained about a relevant organ, comprising:

modeling the relevant organ, based on its geometry;

modeling the anatomical constraints, which limit accessibility to the relevant organ;

obtaining a collection of views of the modeled relevant organ, within the modeled anatomical constraints;

providing a scoring function, by which any set of at least one view, from the collection of views, is scorable with a score that rates the information obtained from the modeled relevant organ, by the set;

forming sets of views from the collection of views and scoring them, with the scoring function; and

selecting one of the sets of views, from the collection of views, based on its score, as the predefined set of radioactive-emission measurement views.

56. A method of functional imaging, tailored for imaging from the esophagus, and optimized with respect to the functional information gained about a relevant organ, comprising:

modeling the relevant organ, based on its geometry;

modeling anatomical constraints, which limit accessibility to the relevant organ;

obtaining a collection of views of the modeled relevant organ, within the modeled anatomical constraints;

providing a scoring function, by which any set of at least one view, from the collection of views is scorable with a score that rates information obtained from the modeled relevant organ, by the set;

forming sets of views from the collection of views and scoring them, with the scoring function;

selecting one of the sets of views from the collection of views, based on its score, as a predefined set of views; and

performing diagnostic radioactive-emission measurements of an in-vivo relevant organ that corresponds to the relevant organ that has been modeled, selectively at the predefined set of views.

57. A method of zooming in on a location of a suspected pathological feature within a relevant organ, during diagnostic radioactive-emission measurements from the esophagus, in vivo, comprising:

modeling the relevant organ, based on its geometry;

modeling anatomical constraints, which limit accessibility to the relevant organ;

obtaining a first collection of views of the modeled relevant organ, within the modeled anatomical constraints;

providing a first scoring function, by which any set of at least one view, from any collection of views is scorable with a score that rates information obtained from the modeled relevant organ by the set;

forming sets of views from the first collection of views and scoring them, with the first scoring function;

selecting one of the sets of views from the first collection of views, based on its score, as a predefined set of views;

performing diagnostic radioactive-emission measurements of an in-vivo relevant organ that corresponds to the relevant organ that has been modeled, selectively at the predefined set of views;

identifying the suspected pathological feature;

modeling the suspected pathological feature within the modeled relevant organ;

modeling anatomical constraints, which limit accessibility to the suspected pathological feature within the relevant organ;

obtaining a second collection of views of the modeled location of the suspected pathological feature within the modeled relevant organ and the modeled anatomical constraints;

providing a second scoring function;

forming sets of views from the second collection of views and scoring them, with the second scoring function;

selecting one of the sets of views from the second collection of views, based on its score, as a predefined pathology set of views; and

performing diagnostic radioactive-emission measurements of the in-vivo suspected pathological feature, selectively at the predefined pathology set of views.

58. A method for identifying a radioactive-emission-measuring-probe design for imaging from an esophagus, the design being optimized with respect to functional information gained about a relevant organ, the method comprising:

modeling a relevant organ, based on its geometry;

modeling anatomical constraints, which limit accessibility to the relevant organ;

obtaining representative collections of views of the modeled relevant organ, within the modeled anatomical constraints, for different probe designs;

providing a scoring function, by which each representative collection of views, associated with a specific probe design, is scorable with a score that rates information, obtained from the relevant organ;

scoring the representative collections of views of the different probe designs; and

selecting a probe design for imaging from the esophagus, based on the score of its representative collection of views.

59. A radioactive-emission-measuring-probe system, defining a frame of reference and tailored for cardiac imaging, comprising:

at least one assembly, defining a cylindrical coordinate system of x;r, registered to the frame of reference, and comprising:

a row of at least two detecting units, each detecting unit being adapted for an oscillatory motion about r;

motion transfer systems, equal in number to the number of detecting units, each of the motion transfer systems being in mechanical communication with one of the detecting unit, for providing it with the oscillatory motion about r;

a secondary motion provider, in mechanical communication with the motion transfer systems, for providing the motion thereto;

an inner housing, for housing the row of at least two detecting units; and

a motion provider, in mechanical communication with the inner housing for providing it with rotational motion about x; and

a housing for the at least one assembly.

60. A method for predefining a set of radioactive-emission measurement views, for functional imaging, tailored for cardiac imaging, and optimized with respect to the functional information gained about the heart, comprising:

modeling the heart, based on its geometry;

modeling the anatomical constraints, which limit accessibility to the heart;

obtaining a collection of views of the modeled heart, within the modeled anatomical constraints;

providing a scoring function, by which any set of at least one view, from the collection of views, is scorable with a score that rates the information obtained from the modeled heart, by the set;

forming sets of views from the collection of views and scoring them, with the scoring function; and

selecting one of the sets of views, from the collection of views, based on its score, as the predefined set of radioactive-emission measurement views.

61. A method of functional imaging, tailored for cardiac imaging, and optimized with respect to the functional information gained about the heart, comprising:

modeling the heart, based on its geometry;

modeling anatomical constraints, which limit accessibility to the heart;

obtaining a collection of views of the modeled heart, within the modeled anatomical constraints;

providing a scoring function, by which any set of at least one view, from the collection of views is scorable with a score that rates information obtained from the modeled heart, by the set;

forming sets of views from the collection of views and scoring them, with the scoring function;

selecting one of the sets of views from the collection of views, based on its score, as a predefined set of views; and

performing diagnostic radioactive-emission measurements of an in-vivo heart that corresponds to the heart that has been modeled, selectively at the predefined set of views.

62. A method of zooming in on a location of a suspected pathological feature within a heart, during diagnostic radioactive-emission measurements, in vivo, comprising:

modeling the heart, based on its geometry;

modeling anatomical constraints, which limit accessibility to the heart;

obtaining a first collection of views of the modeled heart, within the modeled anatomical constraints;

providing a first scoring function, by which any set of at least one view, from any collection of views is scorable with a score that rates information obtained from the modeled heart by the set;

forming sets of views from the first collection of views and scoring them, with the first scoring function;

selecting one of the sets of views from the first collection of views, based on its score, as a predefined set of views;

performing diagnostic radioactive-emission measurements of an in-vivo heart that corresponds to the heart that has been modeled, selectively at the predefined set of views;

identifying the suspected pathological feature;

modeling the suspected pathological feature within the modeled heart;

modeling anatomical constraints, which limit accessibility to the suspected pathological feature within the heart;

obtaining a second collection of views of the modeled location of the suspected pathological feature within the modeled heart and the modeled anatomical constraints;

providing a second scoring function;

forming sets of views from the second collection of views and scoring them, with the second scoring function;

selecting one of the sets of views from the second collection of views, based on its score, as a predefined pathology set of views; and

performing diagnostic radioactive-emission measurements of the in-vivo suspected pathological feature, selectively at the predefined pathology set of views.

63. A method for identifying a radioactive-emission-measuring-probe design optimized with respect to functional information gained about a heart, comprising:

modeling a heart, based on its geometry;

modeling anatomical constraints, which limit accessibility to the heart;

obtaining representative collections of views of the modeled heart, within the modeled anatomical constraints, for different probe designs;

providing a scoring function, by which each representative collection of views, associated with a specific probe design, is scorable with a score that rates information, obtained from the heart;

scoring the representative collections of views of the different probe designs; and

selecting a probe design, based on the score of its representative collection of views.

an admission that such reference is available as prior art to the present invention.

64. A dual imaging method, comprising:

providing a bed, adapted for motion through a three-dimensional structural imager and a radioactive-emission-measuring probe;

automatically imaging a body structure of a patient on the bed, by the three-dimensional structural imager, which defines a frame of reference;

automatically imaging the body structure of the patient on the bed, by the radioactive-emission-measuring probe, co-registered to the same frame of reference.

65. The dual imaging method of claim 64, wherein the radioactive-emission-measuring probe and the three-dimensional structural imager image the body structure substantially at a same rate, so that the bed carries the patient through both, at a constant speed.

66. The dual imaging method of claim 64, wherein the structural imager is a CT.

67. The dual imaging method of claim 64, wherein the structural imager is an MRI.

68. The dual imaging system of claim 64, wherein the radioactive-emission-measuring probe is shaped substantially as an arc, for viewing one side of the patient.

69. The dual imaging system of claim 64, wherein the radioactive-emission-measuring probe is shaped substantially as two arcs, for viewing the two sides of the patient, simultaneously.

70. The dual imaging system of claim 69, wherein the bed is formed as a stretcher, of a material which is substantially transparent to radioactive emission, for viewing the two sides of the patient, simultaneously, when the patient is lying down.

71. The dual imaging method of claim 64, wherein the radioactive-emission-measuring probe is shaped substantially as a circle, for viewing the two sides of the patient, simultaneously.

72. The dual imaging method of claim 71, wherein the bed is formed as a stretcher, of a material which is substantially transparent to radioactive emission, for viewing the two sides of the patient, simultaneously, when the patient is lying down.

73. A radioactive-emission-measuring probe, comprising:

a housing, which defines a frame of reference; and

an internal structure which includes a plurality of detecting units, each adapted for at least one rotational motion, for providing views from different orientations, with respect to the housing, for obtaining radioactive-emission measurements from a plurality of views of different orientations, while the housing remains fixed in place.

74. The radioactive-emission-measuring probe of claim 73, wherein the radioactive-emission-measuring probe is shaped substantially as an arc, for viewing one side of a patient.

75. The radioactive-emission-measuring probe of claim 73, wherein the radioactive-emission-measuring probe is shaped substantially as two arcs, for viewing the two sides of a patient, simultaneously.

76. The radioactive-emission-measuring probe of claim 75, and further including a bed, formed as a stretcher, of a material which is substantially transparent to radioactive emission, for viewing the two sides of the patient, simultaneously, when the patient is lying down.

77. The radioactive-emission-measuring probe of claim 73, wherein the radioactive-emission-measuring probe is shaped substantially as a circle, for viewing two sides of a patient, simultaneously, when the patient is lying down.

78. The radioactive-emission-measuring probe of claim 77, and further including a bed, formed as a stretcher, of a material which is substantially transparent

to radioactive emission, for viewing the two sides of the patient, simultaneously, when the patient is lying down.

79. A dual imaging system, comprising:

a three-dimensional structural imager, defining a frame of reference and adapted for imaging a body structure;

a radioactive-emission-measuring probe, situated in close proximity to the three-dimensional structural imager, and including:

a housing, registered to the frame of reference; and

an internal structure which includes a plurality of detecting units, each adapted for at least one rotational motion, for providing views from different orientations, with respect to the housing, for obtaining radioactive-emission measurements from a plurality of views of different orientations, while the housing remains fixed in place;

a bed on which a patient is positioned, the bed being mounted on a gantry and being adapted for motion, for automatically carrying the patient into the radioactive-emission-measuring probe and the three-dimensional structural imager, for in-tandem imaging; and

a control unit which controls the operation of the dual imaging system.

80. The dual imaging system of claim 79, wherein the radioactive-emission-measuring probe and the three-dimensional structural imager image the body structure substantially at a same rate, so that the bed carries the patient through both, at a constant speed.

81. The dual imaging system of claim 79, wherein the structural imager is a CT.

82. The dual imaging system of claim 79, wherein the structural imager is an MRI.

83. A dual imaging system of claim 79, comprising:

at least one assembly, defining a cylindrical coordinate system of x;r, registered to the frame of reference, and comprising:

a row of at least two detecting units, each detecting unit being adapted for an oscillatory motion about r, to generate views from different orientations about r and to change its view orientation about r;

motion transfer systems, equal in number to the number of detecting units, each of the motion transfer systems being in mechanical communication with one of the detecting unit, for providing it with the oscillatory motion about r;

a secondary motion provider, in mechanical communication with the motion transfer systems, for providing the motion thereto;

an inner housing, for housing the row of at least two detecting units; and

a motion provider, in mechanical communication with the inner housing for providing it with rotational motion about x, to generate views from different orientations about x and to change the view orientation about x; and

a housing for the at least one assembly.

84. The dual imaging system of claim 83, wherein the body structure relates to an organ.

85. The dual imaging system of claim 83, wherein the body structure relates to a portion of an organ.

86. The dual imaging system of claim 83, wherein the body structure relates to blood vessels.

87. The dual imaging system of claim 83, wherein the body structure relates to a gland.

88. The dual imaging system of claim 83, wherein the body structure is selected from the group consisting of a bone, a ligament, a joint, and a combination thereof.

89. The dual imaging system of claim 83, wherein the body structure relates to a portion of the body.

90. The dual imaging system of claim 83, wherein the body structure relates to a whole body.

91. The dual imaging system of claim 83, wherein the at least one assembly includes at least two assemblies.

92. The dual imaging system of claim 91, wherein the at least two assemblies move, about x, independently of each other.

93. The dual imaging system of claim 91, wherein the at least two assemblies move, about x, in parallel.

94. The dual imaging system of claim 91, wherein the at least two assemblies move, about x, in an antipodal manner.

95. The dual imaging system of claim 91, wherein the at least two assemblies are arranged parallel to each other.

96. The dual imaging system of claim 91, wherein the at least two assemblies are arranged perpendicular to each other.

97. The dual imaging system of claim 83, wherein the at least two detecting units within the at least one assembly move, about r, independently of each other.

98. The dual imaging system of claim 83, wherein the at least two detecting units within the at least one assembly move, about r, in parallel.

99. The dual imaging system of claim 83, wherein the at least two detecting units within the at least one assembly move, about r, in an antipodal manner.

100. The dual imaging system of claim 83, wherein the at least two detecting units comprise at least two blocks, each formed of a plurality of detecting units, each block moving as a single, rigid body.

101. The dual imaging system of claim 100, wherein the at least two blocks within the at least one assembly move, about r, independently of each other.

102. The dual imaging system of claim 100, wherein the at least two blocks within the at least one assembly move, about r, in parallel.

103. The dual imaging system of claim 100, wherein the at least two blocks within the at least one assembly move, about r, in an antipodal manner.

104. The dual imaging system of claim 83, wherein the housing is open on a side facing the patient.

105. The dual imaging system of claim 83, wherein the housing is substantially transparent to radioactive emission.

106. The dual imaging system of claim 83, and further including an ultrasound imager.

107. The dual imaging system of claim 83, and further including a controller, in signal communication with the motion provider and the secondary motion provider of the at least one assembly, for instructing them regarding the motions within the at least one assembly, with respect to the frame of reference, thus providing The dual imaging system with automatic motion about the body structure.

108. The dual imaging system of claim 107, wherein the controller registers the motions of the inner housing and each detecting unit of the at least one assembly, so as to correlate each measurement with the corresponding orientation about x and about r, of the detecting unit that performed the measurement, with respect to the frame of reference.

109. The dual imaging system of claim 107, wherein the controller instructs the motion provider and the secondary motion provider of the at least one assembly, in accordance with a predefined set of views, tailored for imaging the body structure, and optimized with respect to information gained about the body structure, obtained by a method comprising:

modeling the body structure, based on its geometry;

modeling the anatomical constraints, which limit accessibility to the body structure;

obtaining a collection of views of the modeled body structure, within the modeled anatomical constraints;

providing a scoring function, by which any set of at least one view, from the collection of views, is scorable with a score that rates the information obtained from the modeled body structure, by the set;

forming sets of views from the collection of views and scoring them, with the scoring function; and

selecting one of the sets of views, from the collection of views, based on its score, as the predefined set of views.

110. A method of functional imaging, tailored for imaging a body structure, in tandem with a three-dimensional structural imager, and optimized with respect to the functional information gained about a body structure, comprising:

modeling the body structure, based on its geometry;

modeling anatomical constraints, which limit accessibility to the body structure;

obtaining a collection of views of the modeled body structure, within the modeled anatomical constraints;

providing a scoring function, by which any set of at least one view, from the collection of views is scorable with a score that rates information obtained from the modeled body structure, by the set;

forming sets of views from the collection of views and scoring them, with the scoring function;

selecting one of the sets of views from the collection of views, based on its score, as a predefined set of views; and

performing diagnostic radioactive-emission measurements of an in-vivo body structure that corresponds to the body structure that has been modeled, selectively at the predefined set of views.

111. A method of zooming in on a location of a suspected pathological feature within a body structure, during diagnostic radioactive-emission measurements, in tandem with a three-dimensional structural imager, comprising:

modeling the body structure, based on its geometry;

modeling anatomical constraints, which limit accessibility to the body structure;

obtaining a first collection of views of the modeled body structure, within the modeled anatomical constraints;

providing a first scoring function, by which any set of at least one view, from any collection of views is scorable with a score that rates information obtained from the modeled body structure by the set;

forming sets of views from the first collection of views and scoring them, with the first scoring function;

selecting one of the sets of views from the first collection of views, based on its score, as a predefined set of views;

performing diagnostic radioactive-emission measurements of an in-vivo body structure that corresponds to the body structure that has been modeled, selectively at the predefined set of views;

identifying the suspected pathological feature;

modeling the suspected pathological feature within the modeled body structure;

modeling anatomical constraints, which limit accessibility to the suspected pathological feature within the body structure;

obtaining a second collection of views of the modeled location of the suspected pathological feature within the modeled body structure and the modeled anatomical constraints;

providing a second scoring function;

forming sets of views from the second collection of views and scoring them, with the second scoring function;

selecting one of the sets of views from the second collection of views, based on its score, as a predefined pathology set of views; and

performing diagnostic radioactive-emission measurements of the in-vivo suspected pathological feature, selectively at the predefined pathology set of views.

112. A method for identifying a radioactive-emission-measuring-probe design for imaging in tandem with a three-dimensional structural imager, the design being optimized with respect to functional information gained about a body structure, the method comprising:

modeling a body structure, based on its geometry;

modeling anatomical constraints, which limit accessibility to the body structure;

obtaining representative collections of views of the modeled body structure, within the modeled anatomical constraints, for different probe designs;

providing a scoring function, by which each representative collection of views, associated with a specific probe design, is scorable with a score that rates information, obtained from the body structure;

scoring the representative collections of views of the different probe designs; and

selecting the probe design, from amongst the different probe designs, based on the score of its representative collection of views.

113. A radioactive-emission-measuring-probe, tailored for imaging a brain of a body, comprising:

a frame, shaped for wearing on a head of the body and defining a frame of reference;

a plurality of detecting units, each defining a detecting-unit frame of reference, in cylindrical coordinates of x and r axes, registered to the frame of reference, and each adapted for at least a first rotational motion; and

at least one first motion provider, in communication the plurality of the detecting units, for providing a first rotational motion.

114. A method for predefining a set of radioactive-emission measurement views, for functional imaging, tailored for imaging a brain of a body, and optimized with respect to the functional information gained about the brain, comprising:

modeling the brain, based on its geometry;

modeling the anatomical constraints, which limit accessibility to the brain;

obtaining a collection of views of the modeled brain, within the modeled anatomical constraints;

providing a scoring function, by which any set of at least one view, from the collection of views, is scorable with a score that rates the information obtained from the modeled brain, by the set;

forming sets of views from the collection of views and scoring them, with the scoring function; and

selecting one of the sets of views, from the collection of views, based on its score, as the predefined set of radioactive-emission measurement views.

115. A method of functional imaging, tailored for imaging a brain of a body, and optimized with respect to the functional information gained about the brain, comprising:

modeling the brain, based on its geometry;

modeling anatomical constraints, which limit accessibility to the brain;

obtaining a collection of views of the modeled brain, within the modeled anatomical constraints;

providing a scoring function, by which any set of at least one view, from the collection of views is scorable with a score that rates information obtained from the modeled brain, by the set;

forming sets of views from the collection of views and scoring them, with the scoring function;

selecting one of the sets of views from the collection of views, based on its score, as a predefined set of views; and

performing diagnostic radioactive-emission measurements of an in-vivo brain that corresponds to the brain that has been modeled, selectively at the predefined set of views.

116. A method of zooming in on a location of a suspected pathological feature within a brain of a body, during diagnostic radioactive-emission measurements, in vivo, comprising:

modeling the brain, based on its geometry;

modeling anatomical constraints, which limit accessibility to the brain;

obtaining a first collection of views of the modeled brain, within the modeled anatomical constraints;

providing a first scoring function, by which any set of at least one view, from any collection of views is scorable with a score that rates information obtained from the modeled brain by the set;

forming sets of views from the first collection of views and scoring them, with the first scoring function;

selecting one of the sets of views from the first collection of views, based on its score, as a predefined set of views;

performing diagnostic radioactive-emission measurements of an in-vivo brain that corresponds to the brain that has been modeled, selectively at the predefined set of views;

identifying the suspected pathological feature;

modeling the suspected pathological feature within the modeled brain;

modeling anatomical constraints, which limit accessibility to the suspected pathological feature within the brain;

obtaining a second collection of views of the modeled location of the suspected pathological feature within the modeled brain and the modeled anatomical constraints;

providing a second scoring function;

forming sets of views from the second collection of views and scoring them, with the second scoring function;

selecting one of the sets of views from the second collection of views, based on its score, as a predefined pathology set of views; and

performing diagnostic radioactive-emission measurements of the in-vivo suspected pathological feature, selectively at the predefined pathology set of views.

117. A radioactive-emission-measuring-probe, tailored for imaging a breast of a body, comprising:

first and second plates, operative for compressing a breast between them, and defining a frame of reference;

a plurality of detecting units, arranged against one of the plates, each of the detecting units being adapted for at least a first motion, with respect to the frame of reference; and

at least one first motion provider, in communication the plurality of the detecting units, for providing the first motion.

118. A radioactive-emission-measuring-probe, tailored for imaging a breast of a body, comprising:

a housing, shaped as a cup having a wall and a rim, for fitting over the breast, the housing defining a housing frame of reference;

a vacuum source, for creating a vacuum in the cup, when fitted over the breast, thus stretching the breast;

a plurality of detecting units, arranged within the wall, each adapted for at least a first motion, with respect to the housing frame of reference; and

at least one first motion provider, in communication the plurality of the detecting units, for providing the first motion.

119. A radioactive-emission-measuring probe for the breasts, comprising:

a housing, which defines a frame of reference; and

an internal structure which includes a plurality of detecting units, each adapted for at least one rotational motion, for providing views of the breasts from different orientations, with respect to the housing, for obtaining radioactive-emission measurements of the breasts from a plurality of views of different orientations, while the housing remains fixed in place.

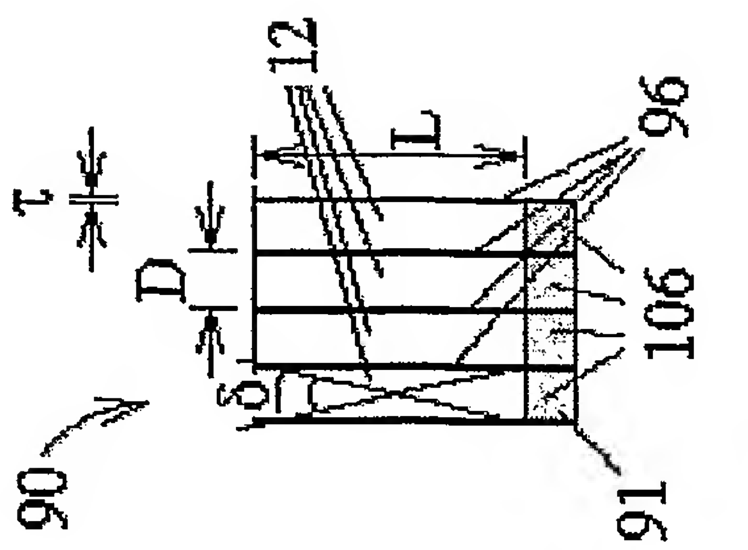


Figure 1B

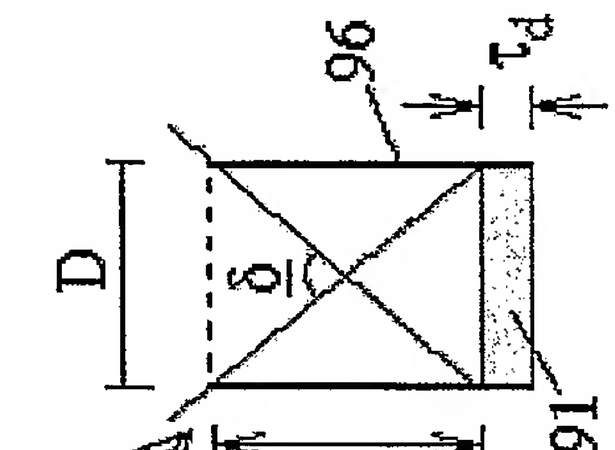


Figure 1A

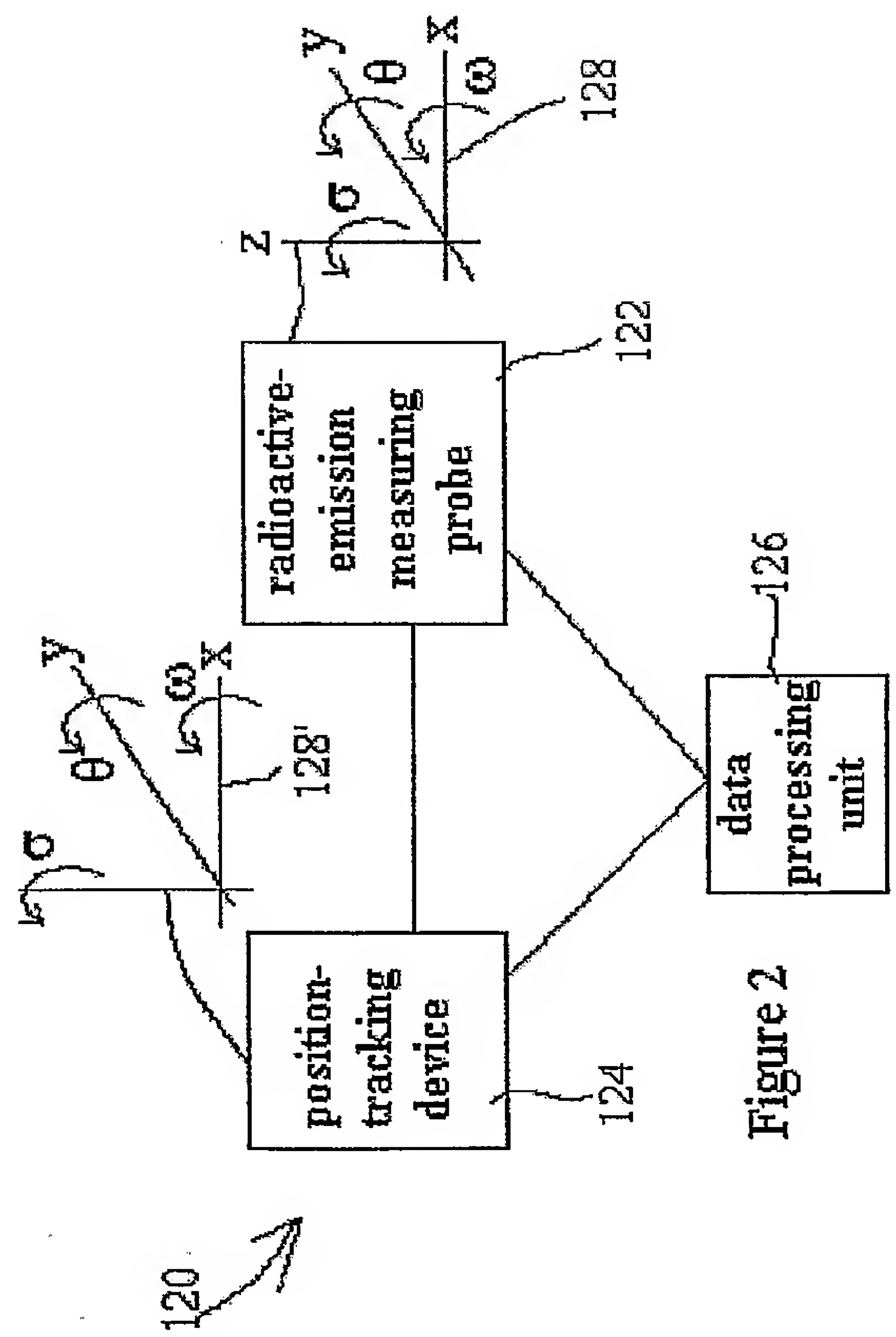


Figure 2

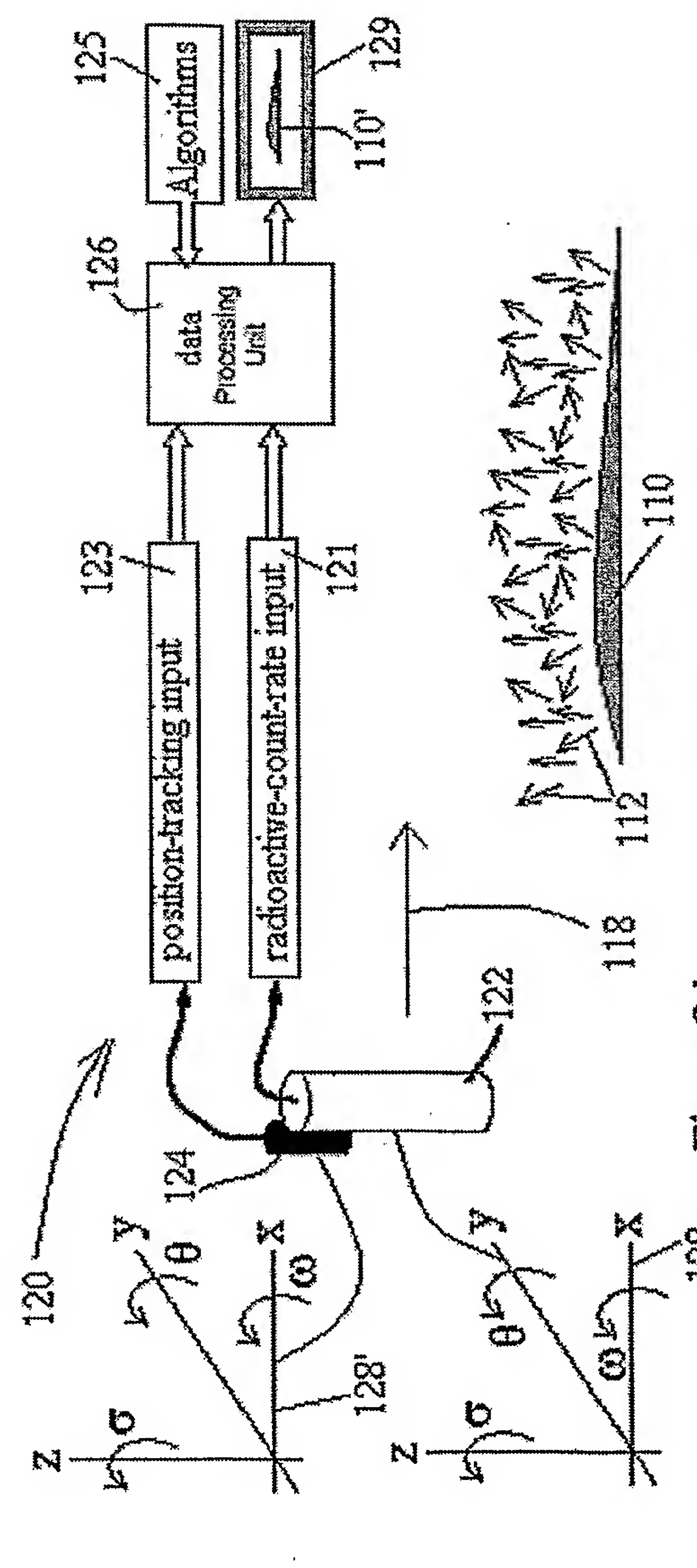


Figure 3A

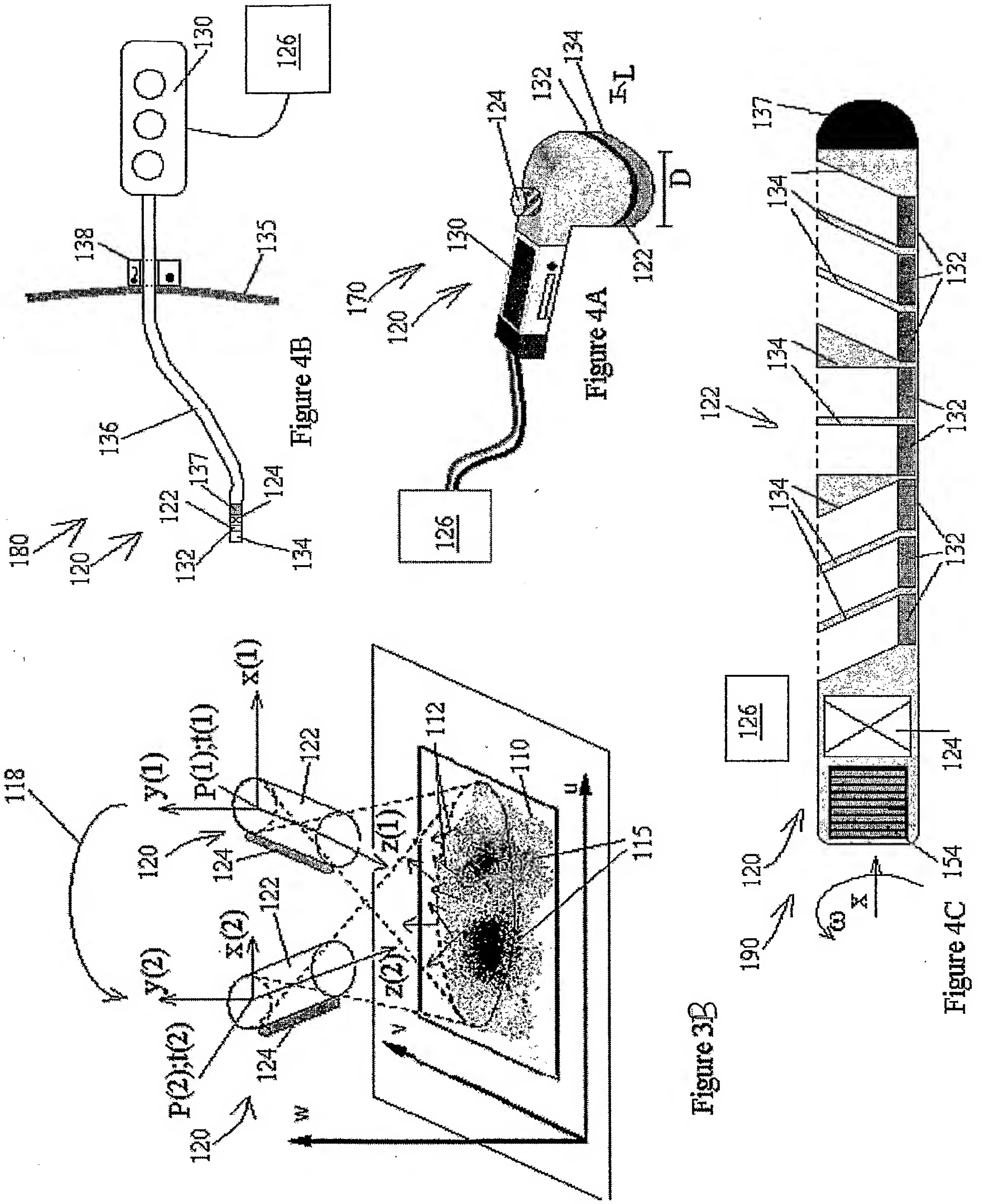


Figure 3B

Figure 4B

Figure 4A

Figure 4C

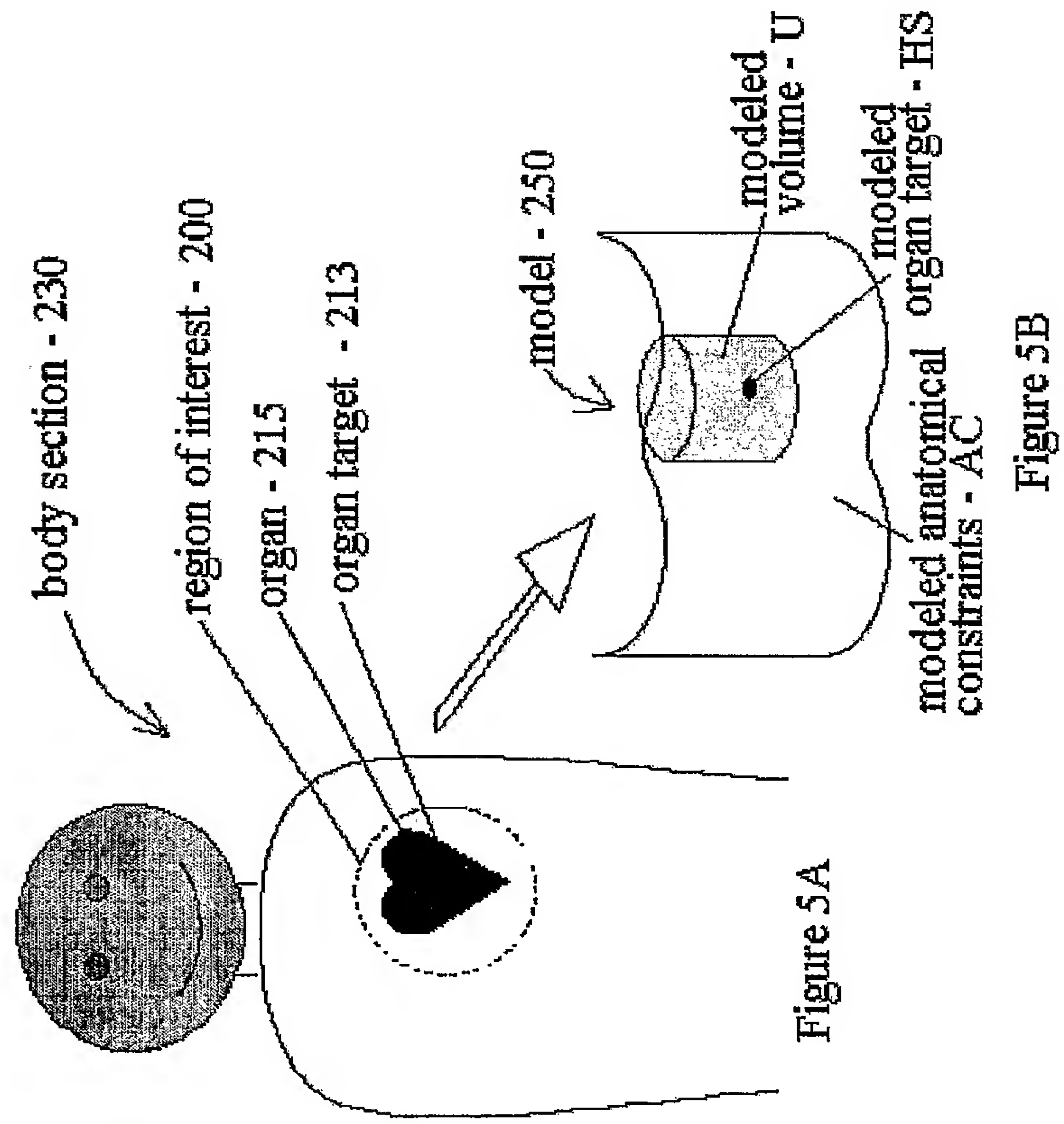


Figure 5A

Figure 5B

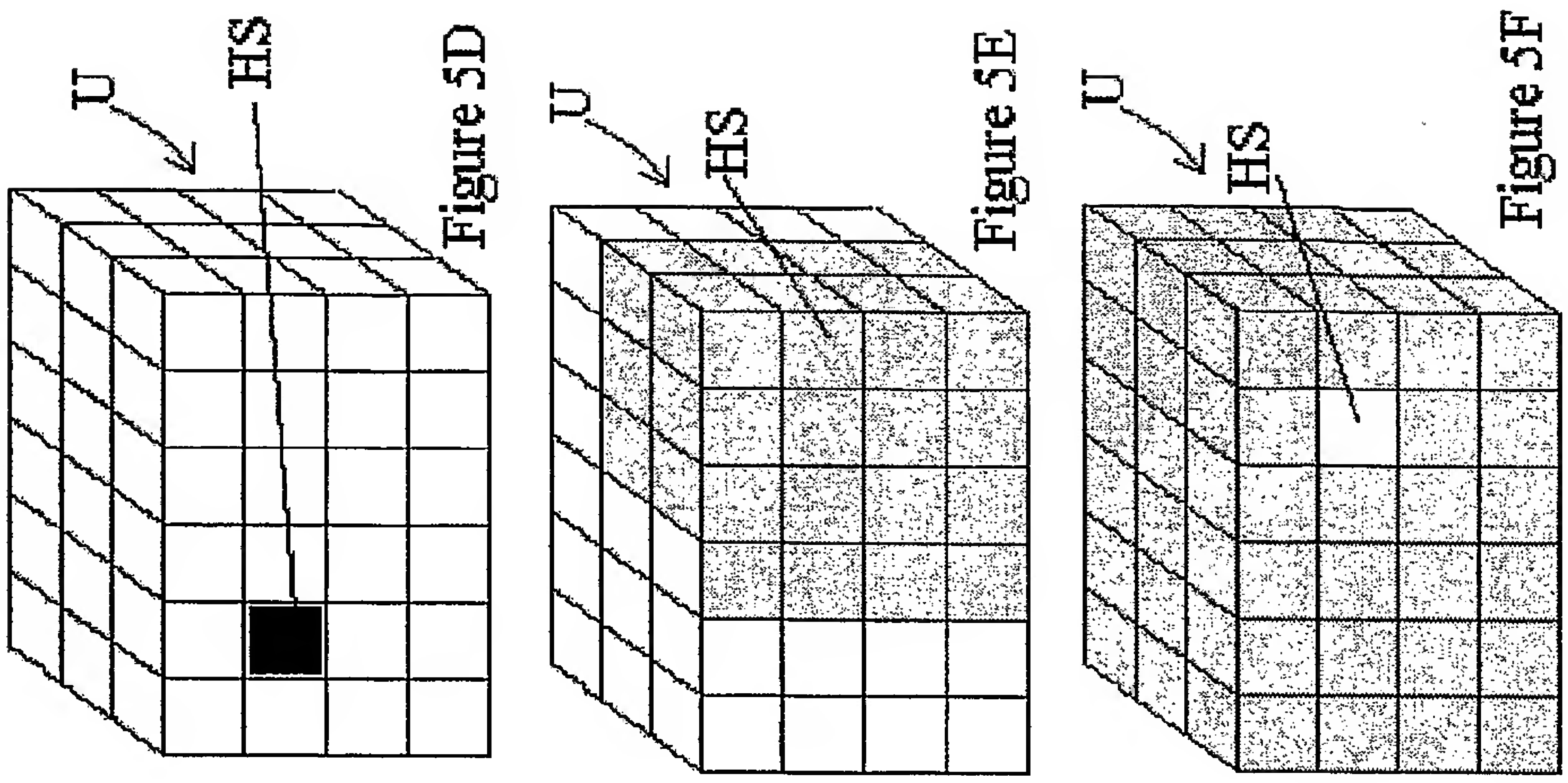
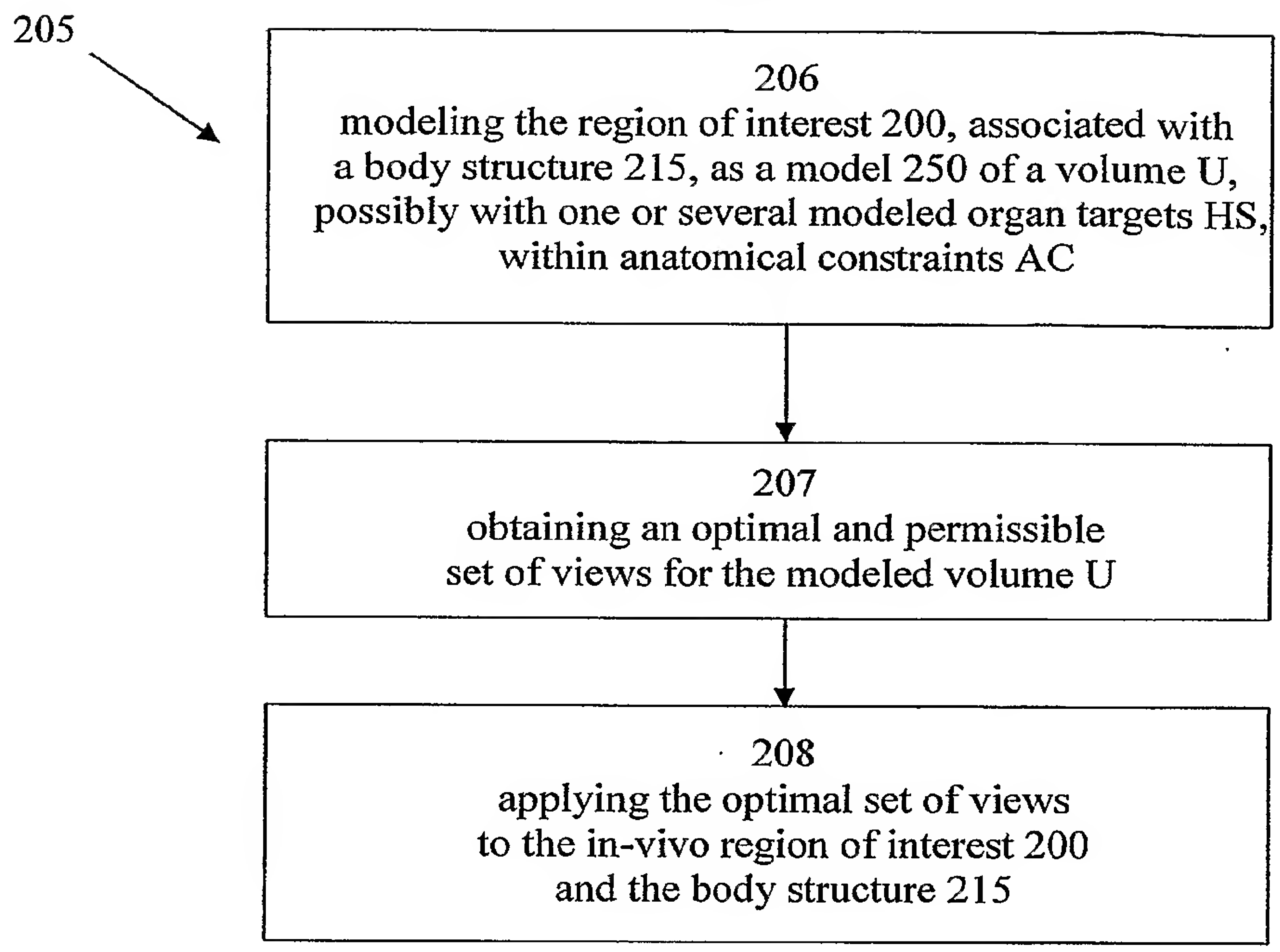


Figure 5D

Figure 5E

Figure 5F

Figure 5C


205
206
modeling the region of interest 200, associated with a body structure 215, as a model 250 of a volume U, possibly with one or several modeled organ targets HS, within anatomical constraints AC
207
obtaining an optimal and permissible set of views for the modeled volume U
208
applying the optimal set of views to the in-vivo region of interest 200 and the body structure 215

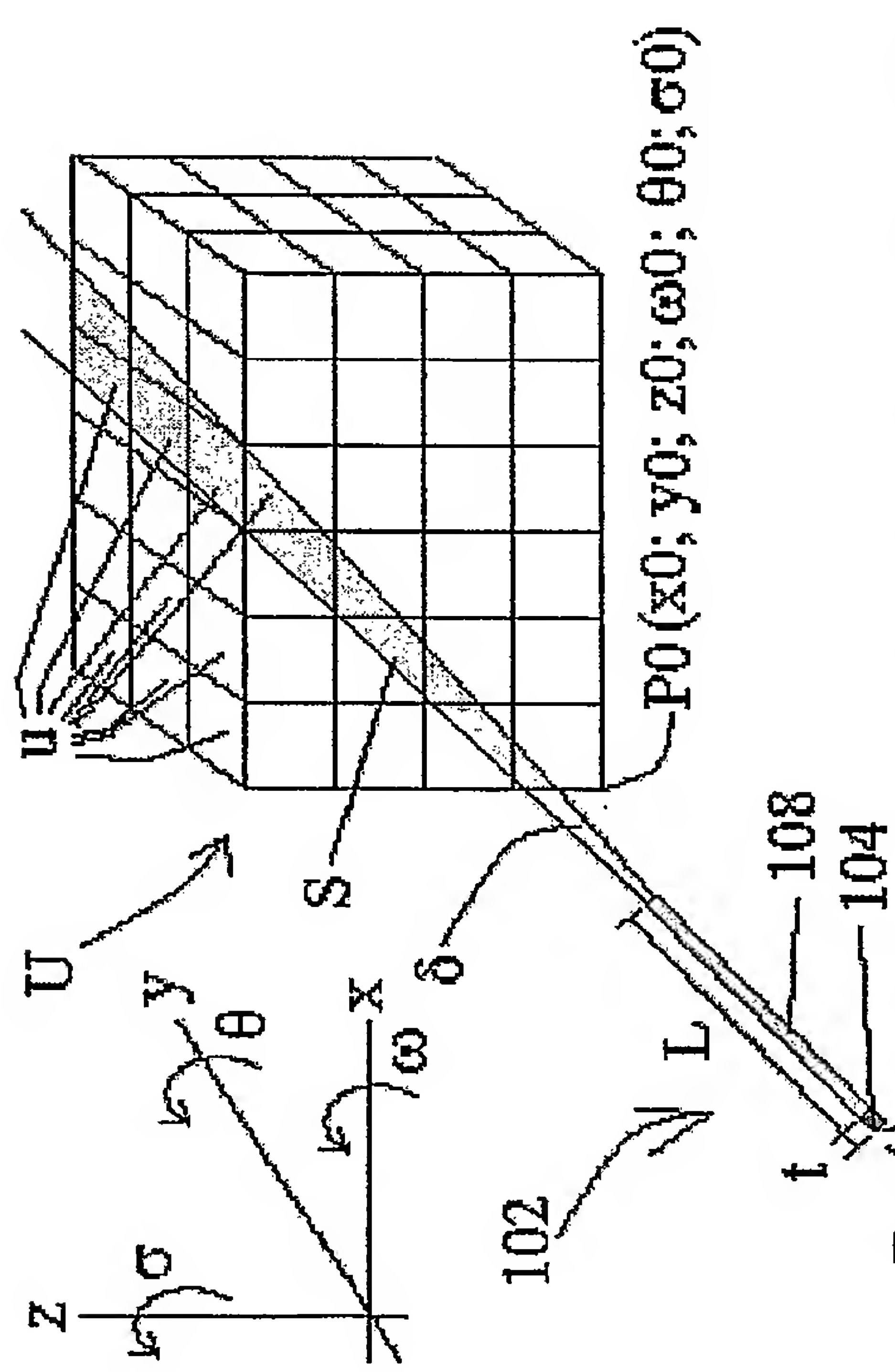


Figure 6A

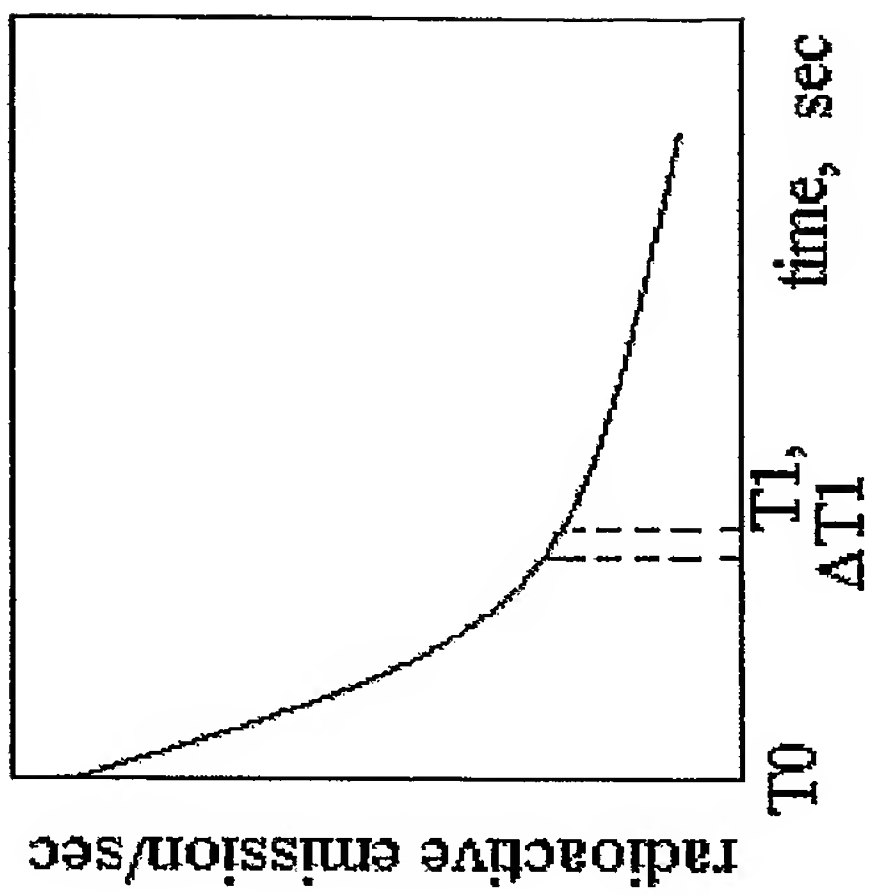


Figure 6B

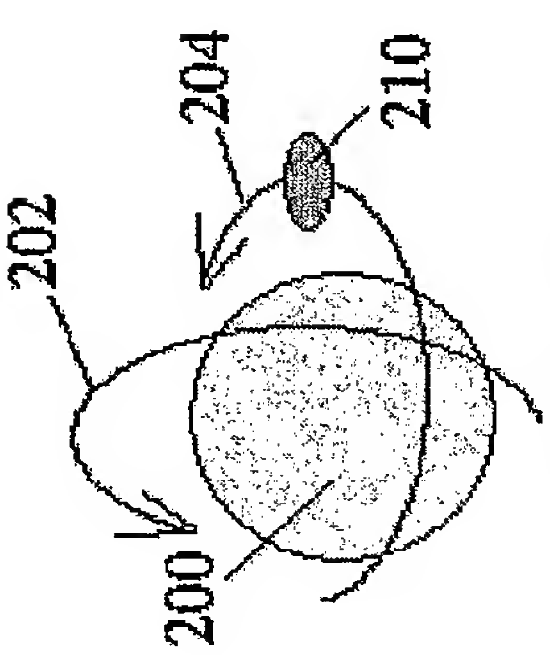


Figure 7A

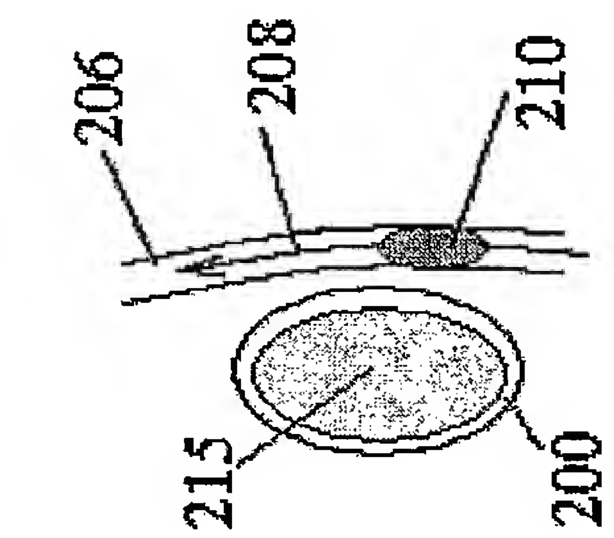


Figure 7B

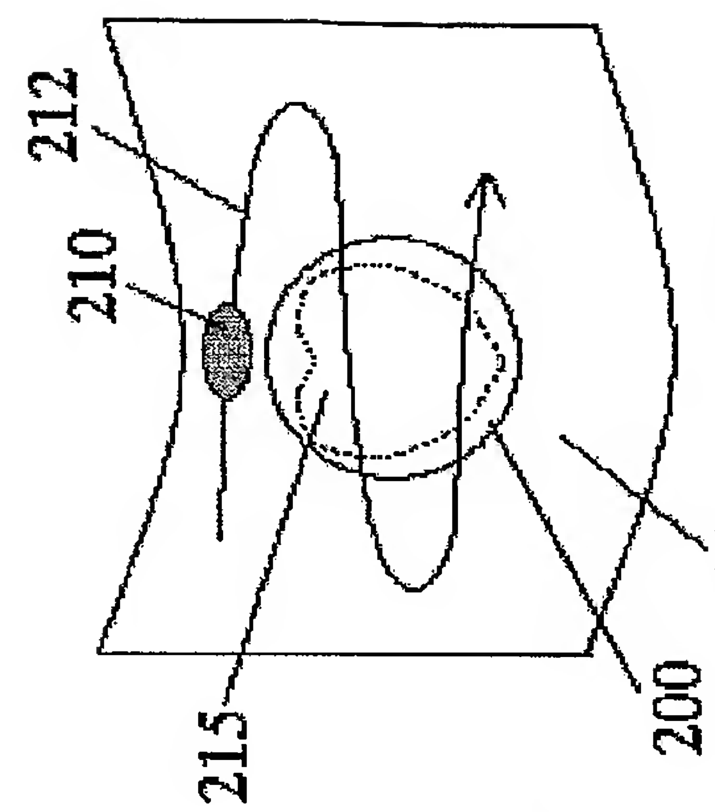
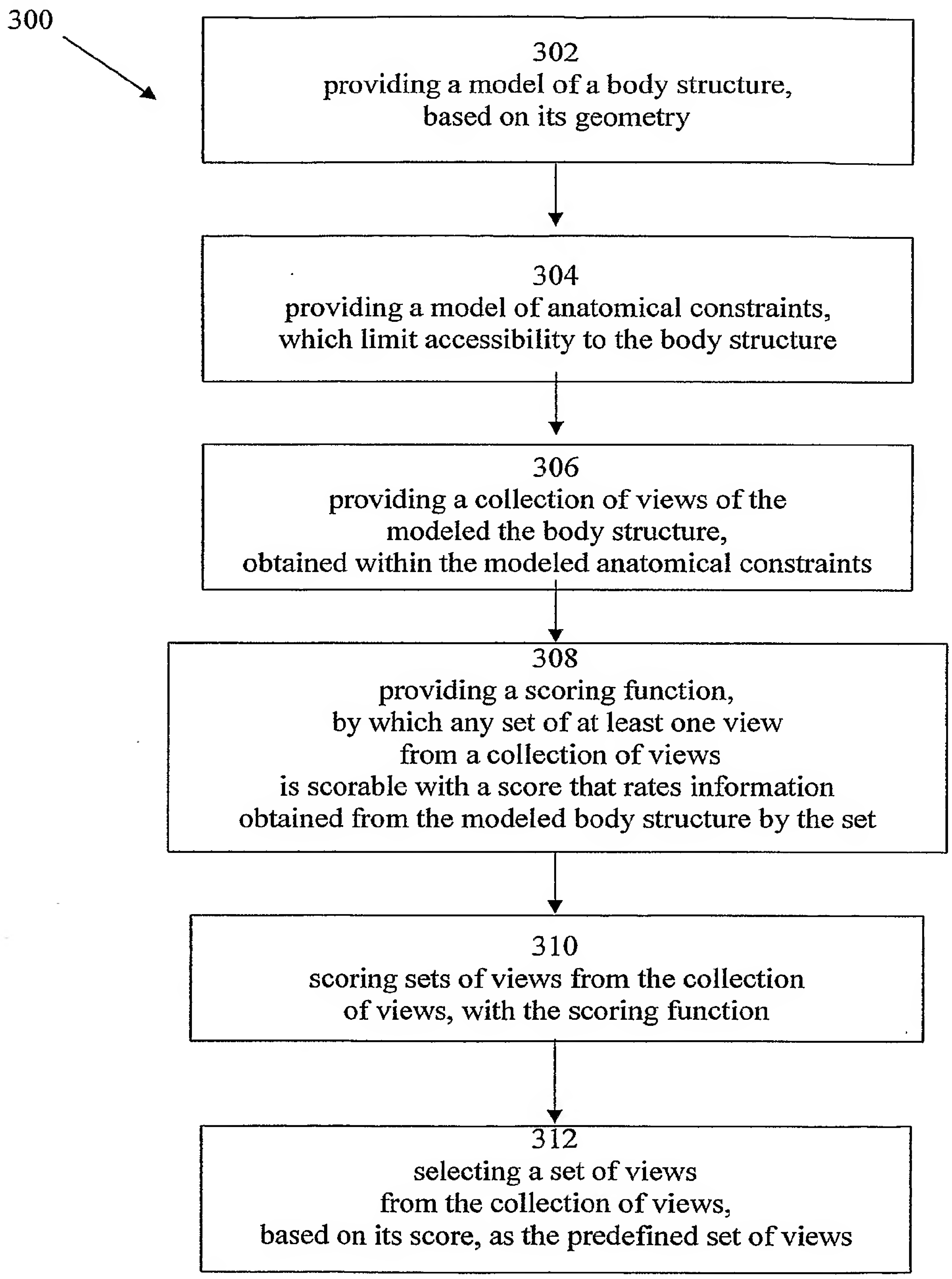


Figure 7C

Figure 8


300
302
providing a model of a body structure,
based on its geometry
304
providing a model of anatomical constraints,
which limit accessibility to the body structure
306
providing a collection of views of the
modeled the body structure,
obtained within the modeled anatomical constraints
308
providing a scoring function,
by which any set of at least one view
from a collection of views
is scorable with a score that rates information
obtained from the modeled body structure by the set
310
scoring sets of views from the collection
of views, with the scoring function
312
selecting a set of views
from the collection of views,
based on its score, as the predefined set of views

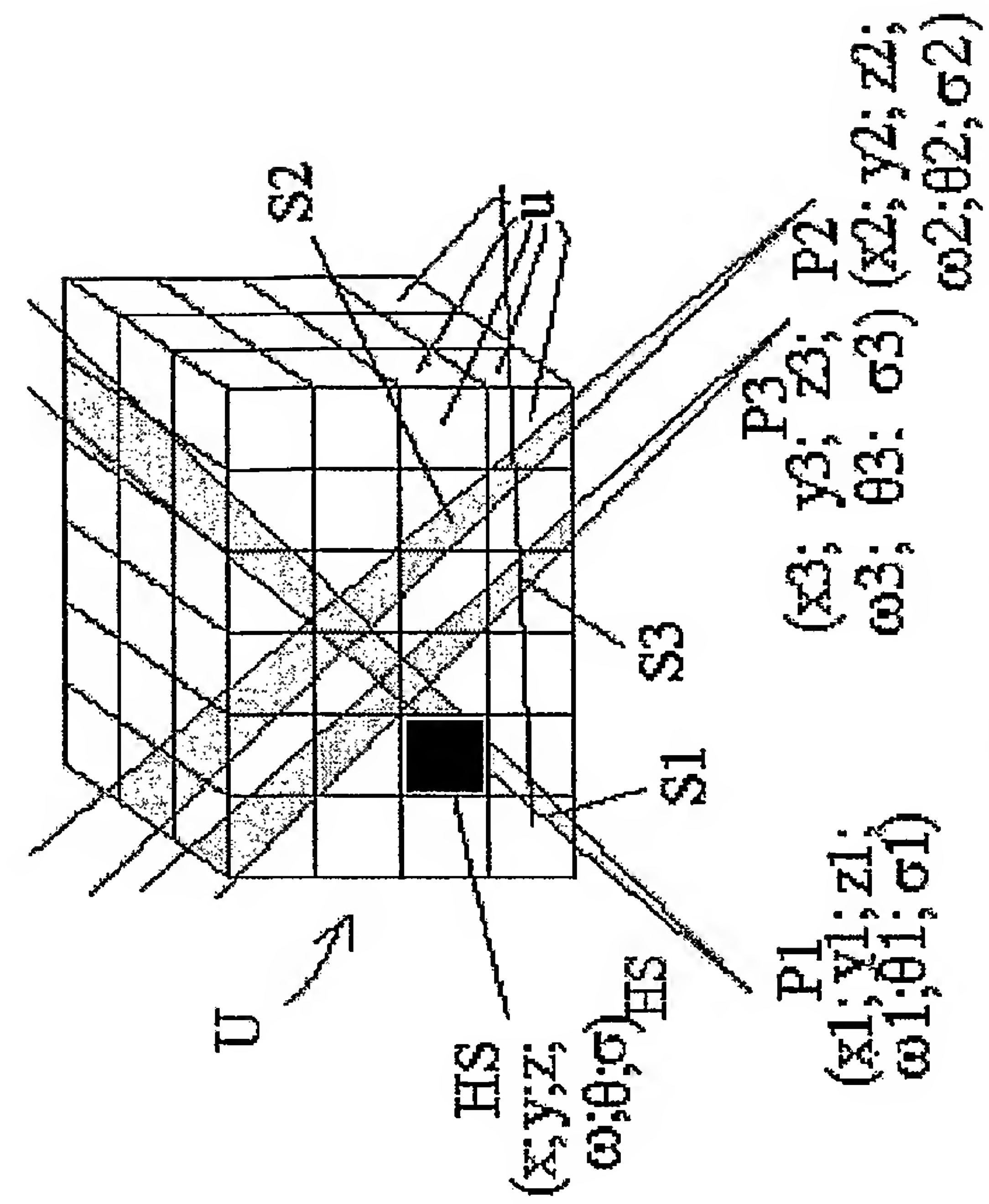


Figure 9B

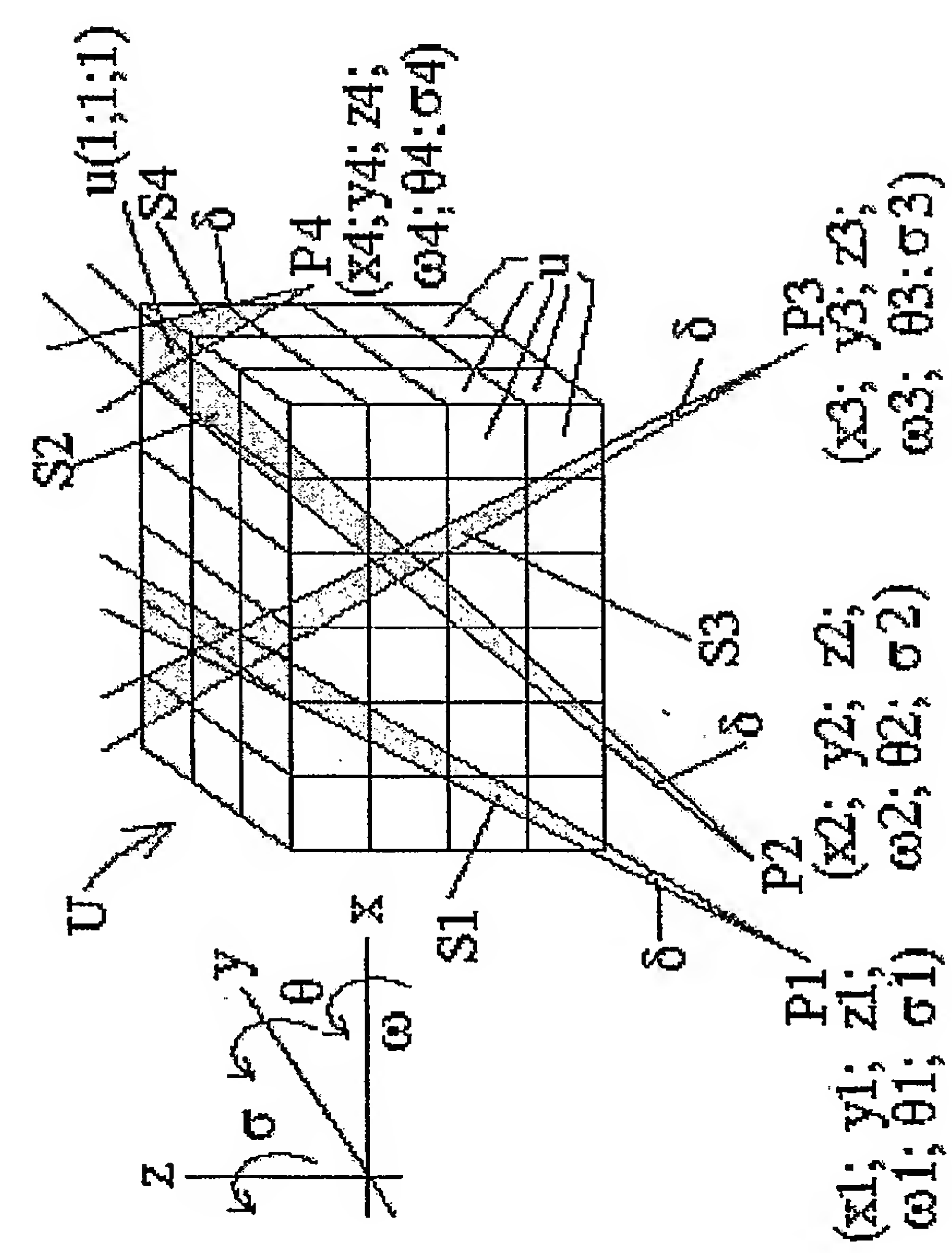


Figure 9A

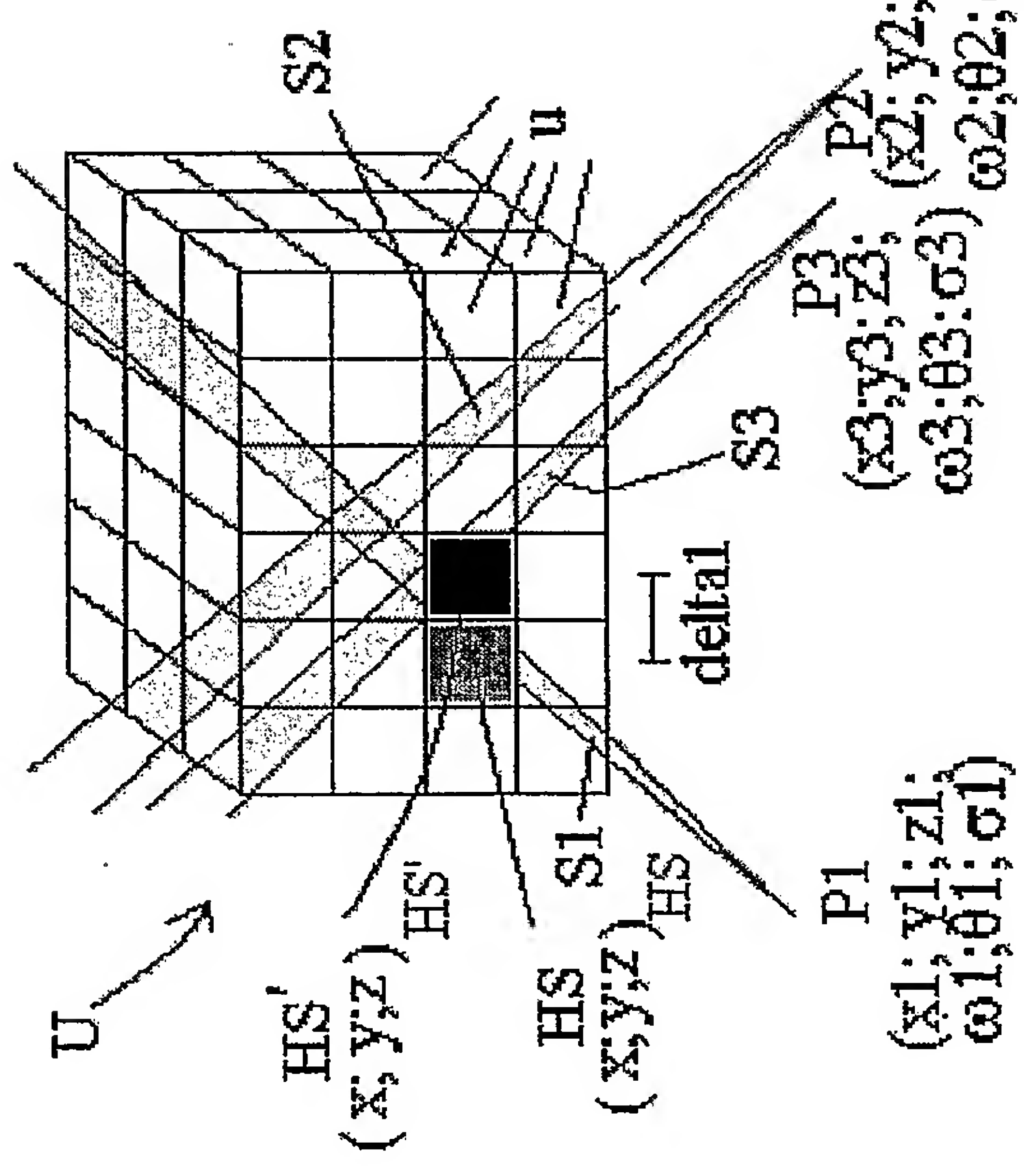


Figure 9C

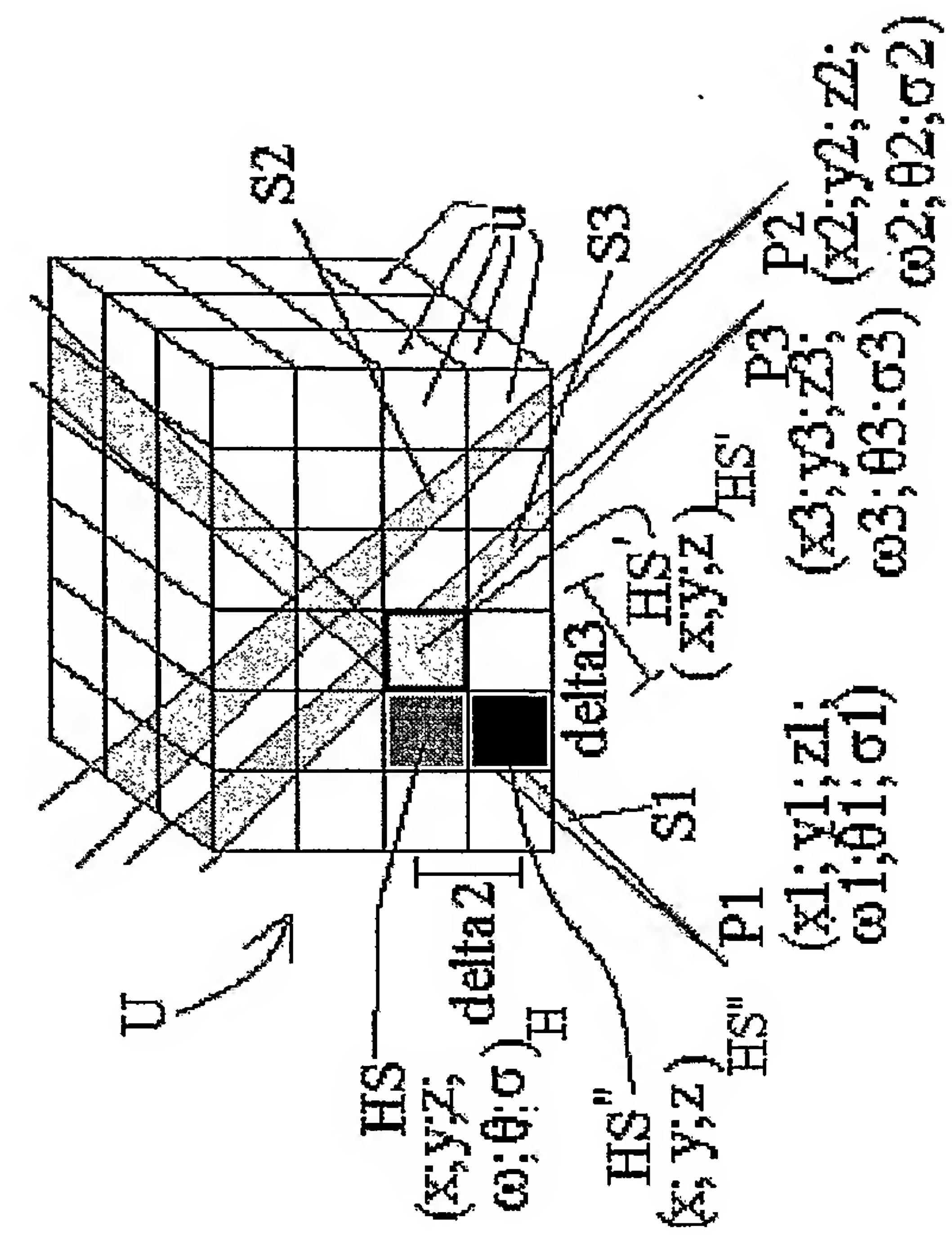


Figure 9D

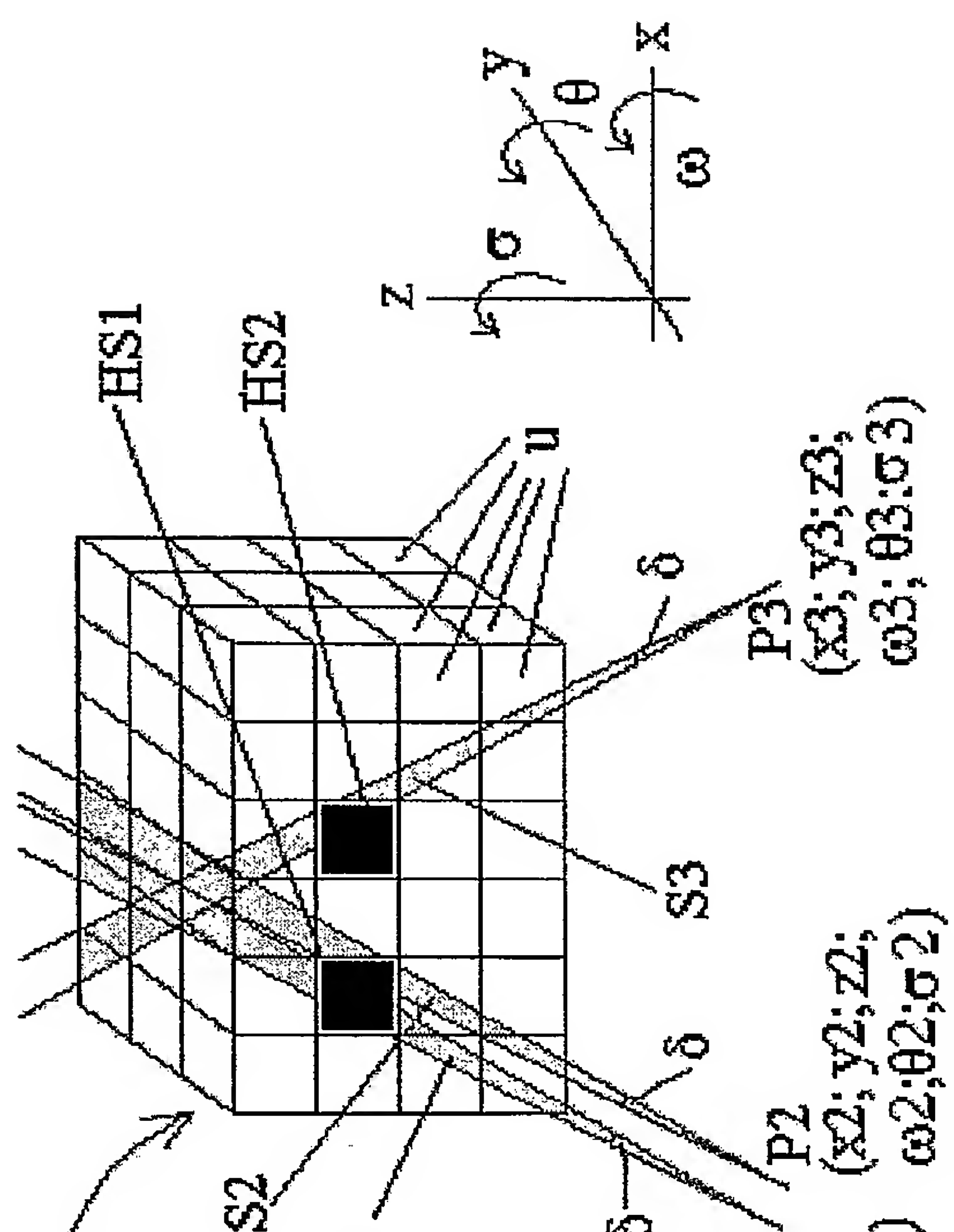


Figure 9 E

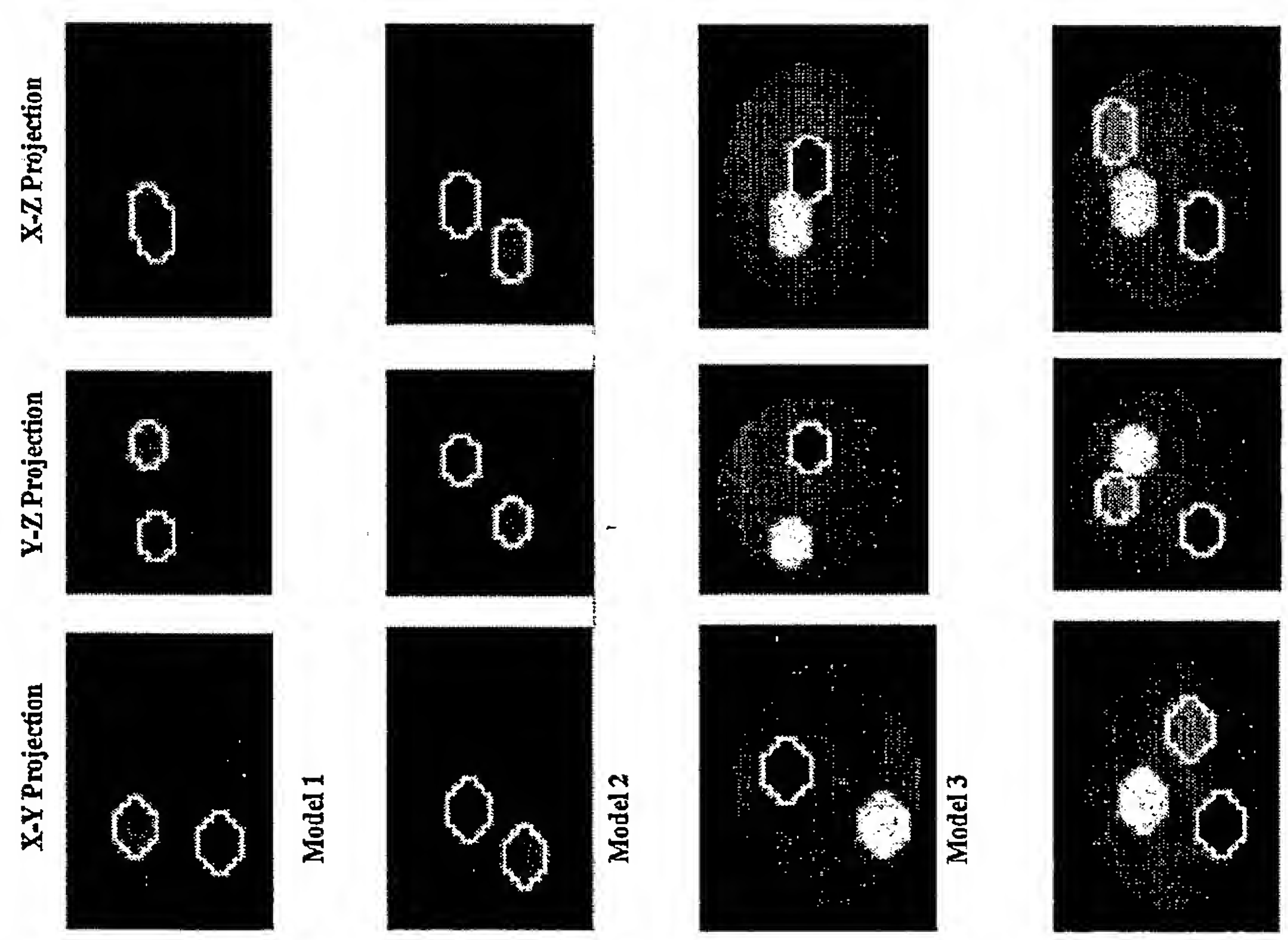
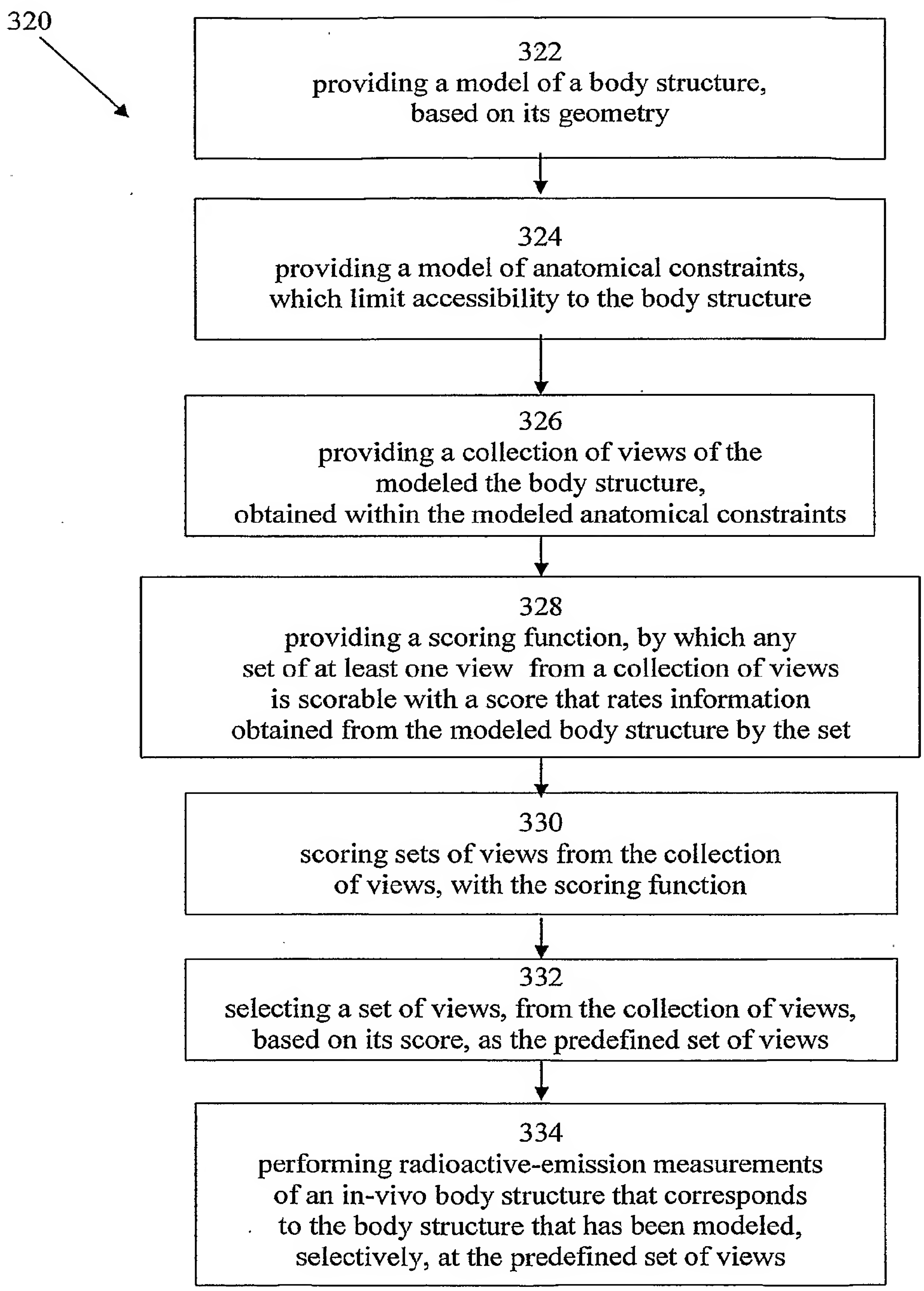

X-Z Projection
Y-Z Projection
X-Y Projection
Model 1
Model 2
Model 3
Model 4

Figure 9F

Figure 10


320
322
providing a model of a body structure,
based on its geometry
324
providing a model of anatomical constraints,
which limit accessibility to the body structure
326
providing a collection of views of the
modeled the body structure,
obtained within the modeled anatomical constraints
328
providing a scoring function, by which any
set of at least one view from a collection of views
is scorable with a score that rates information
obtained from the modeled body structure by the set
330
scoring sets of views from the collection
of views, with the scoring function
332
selecting a set of views, from the collection of views,
based on its score, as the predefined set of views
334
performing radioactive-emission measurements
of an in-vivo body structure that corresponds
to the body structure that has been modeled,
selectively, at the predefined set of views

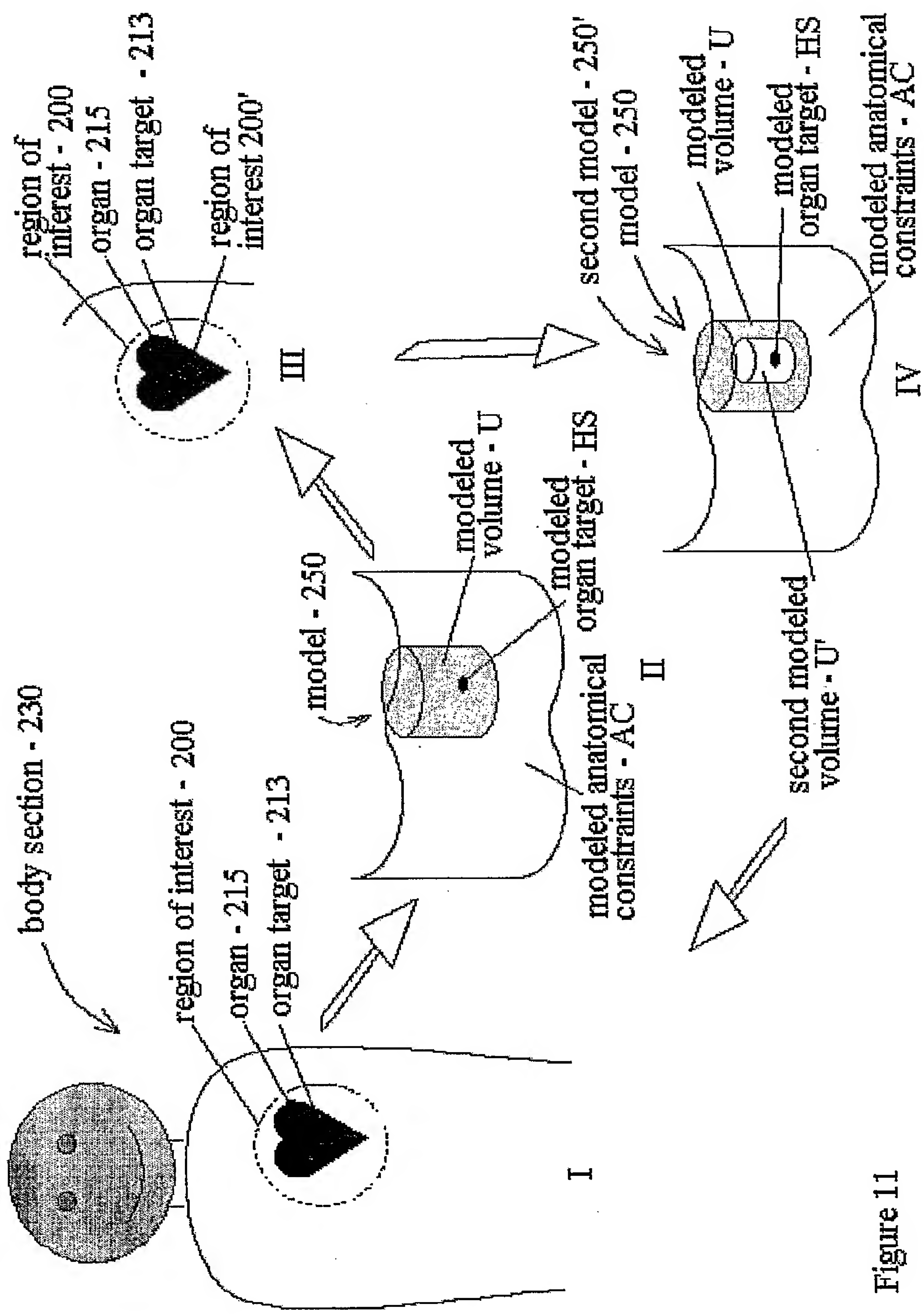

body section - 230
region of interest - 200
organ - 215
organ target - 213
I
model - 250
modeled volume - U
modeled organ target - HS
modeled anatomical constraints - AC
II
region of interest - 200
organ - 215
organ target - 213
region of interest 200'
III
second model - 250'
model - 250
modeled volume - U
modeled organ target - HS
modeled anatomical constraints - AC
second modeled volume - U'
IV

Figure 11

Figure 12

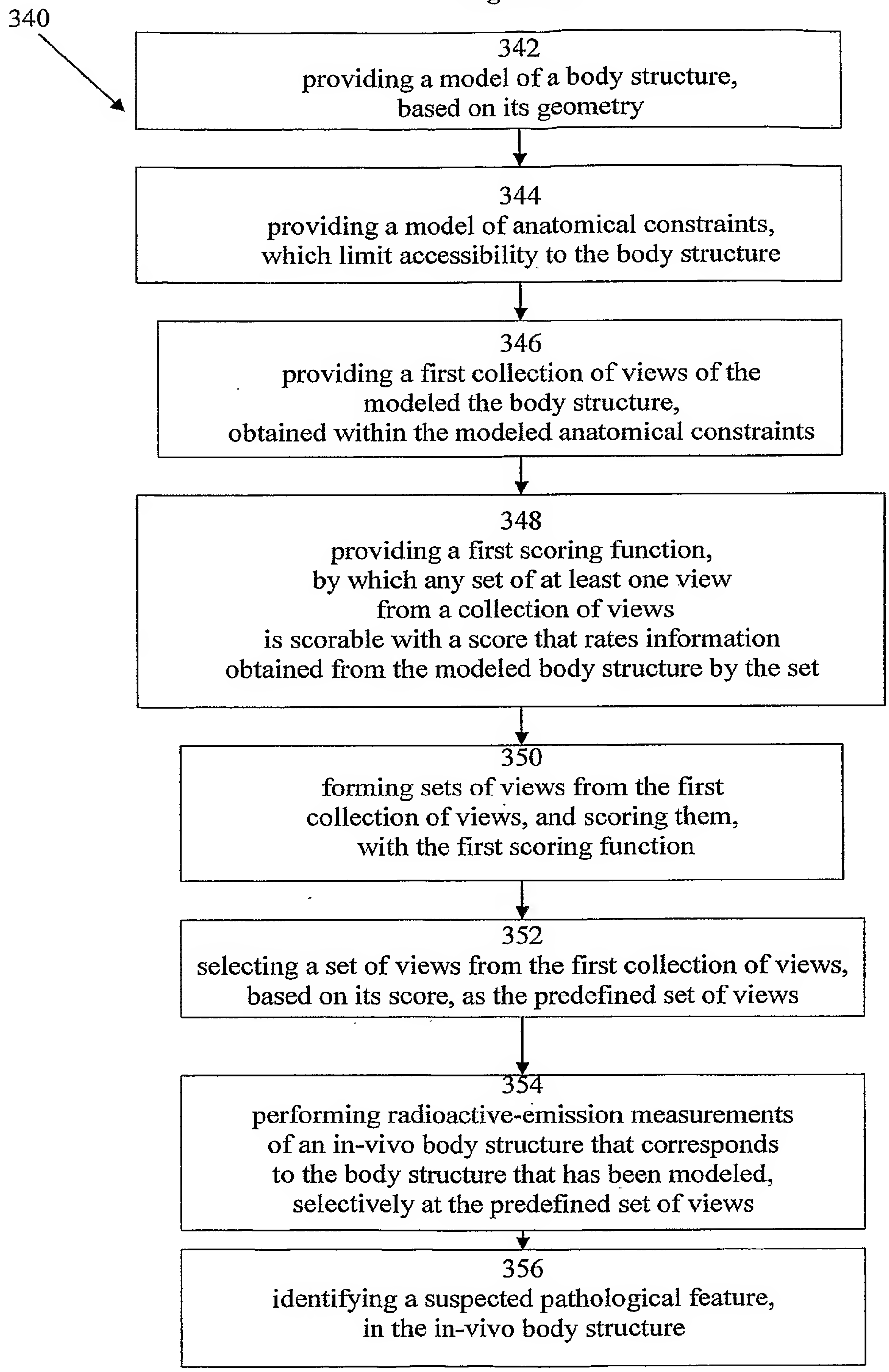
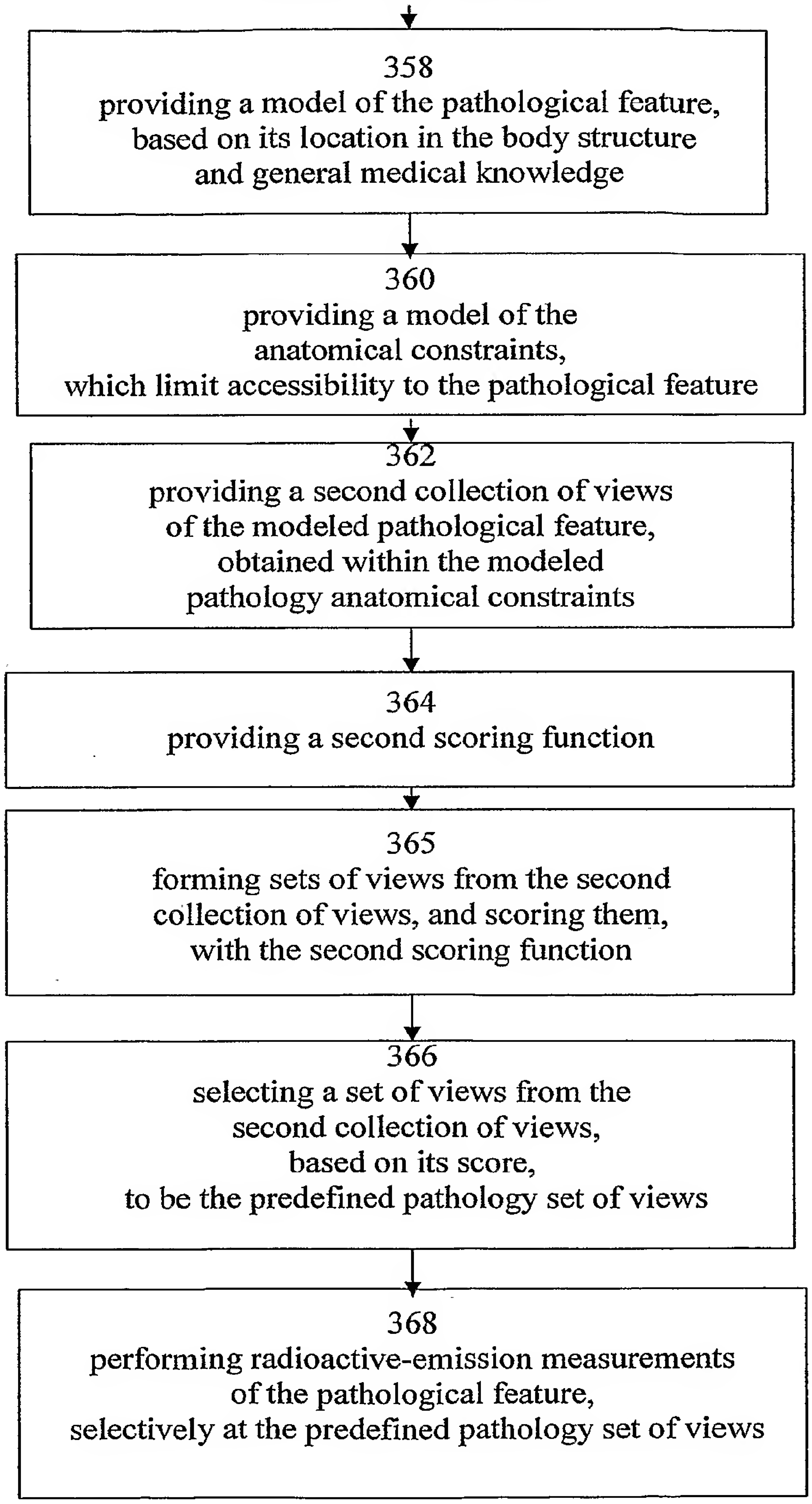

340
342
providing a model of a body structure,
based on its geometry
344
providing a model of anatomical constraints,
which limit accessibility to the body structure
346
providing a first collection of views of the
modeled the body structure,
obtained within the modeled anatomical constraints
348
providing a first scoring function,
by which any set of at least one view
from a collection of views
is scorable with a score that rates information
obtained from the modeled body structure by the set
350
forming sets of views from the first
collection of views, and scoring them,
with the first scoring function
352
selecting a set of views from the first collection of views,
based on its score, as the predefined set of views
354
performing radioactive-emission measurements
of an in-vivo body structure that corresponds
to the body structure that has been modeled,
selectively at the predefined set of views
356
identifying a suspected pathological feature,
in the in-vivo body structure

Figure 12 (continued)



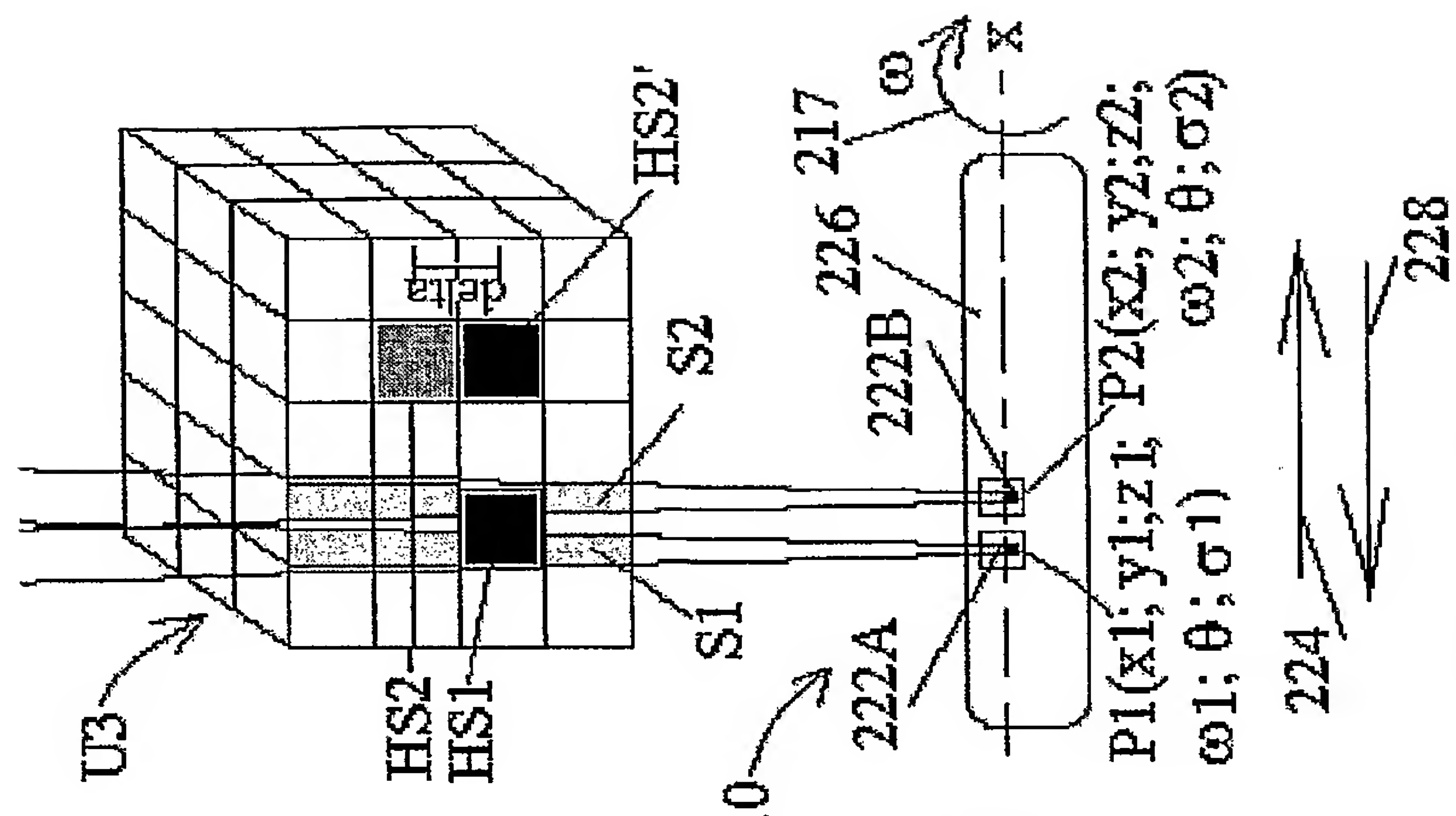


Figure 13C

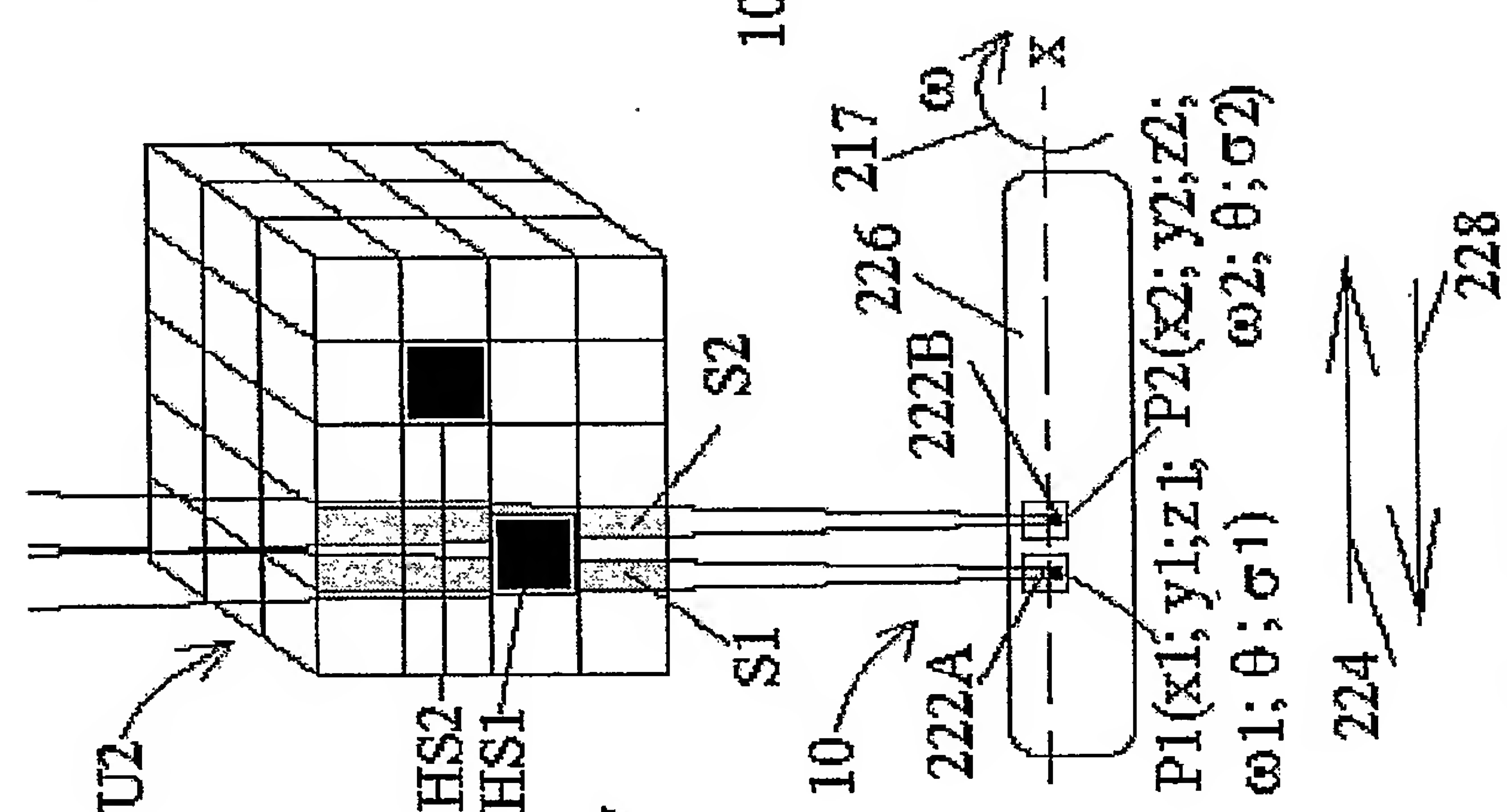


Figure 13B

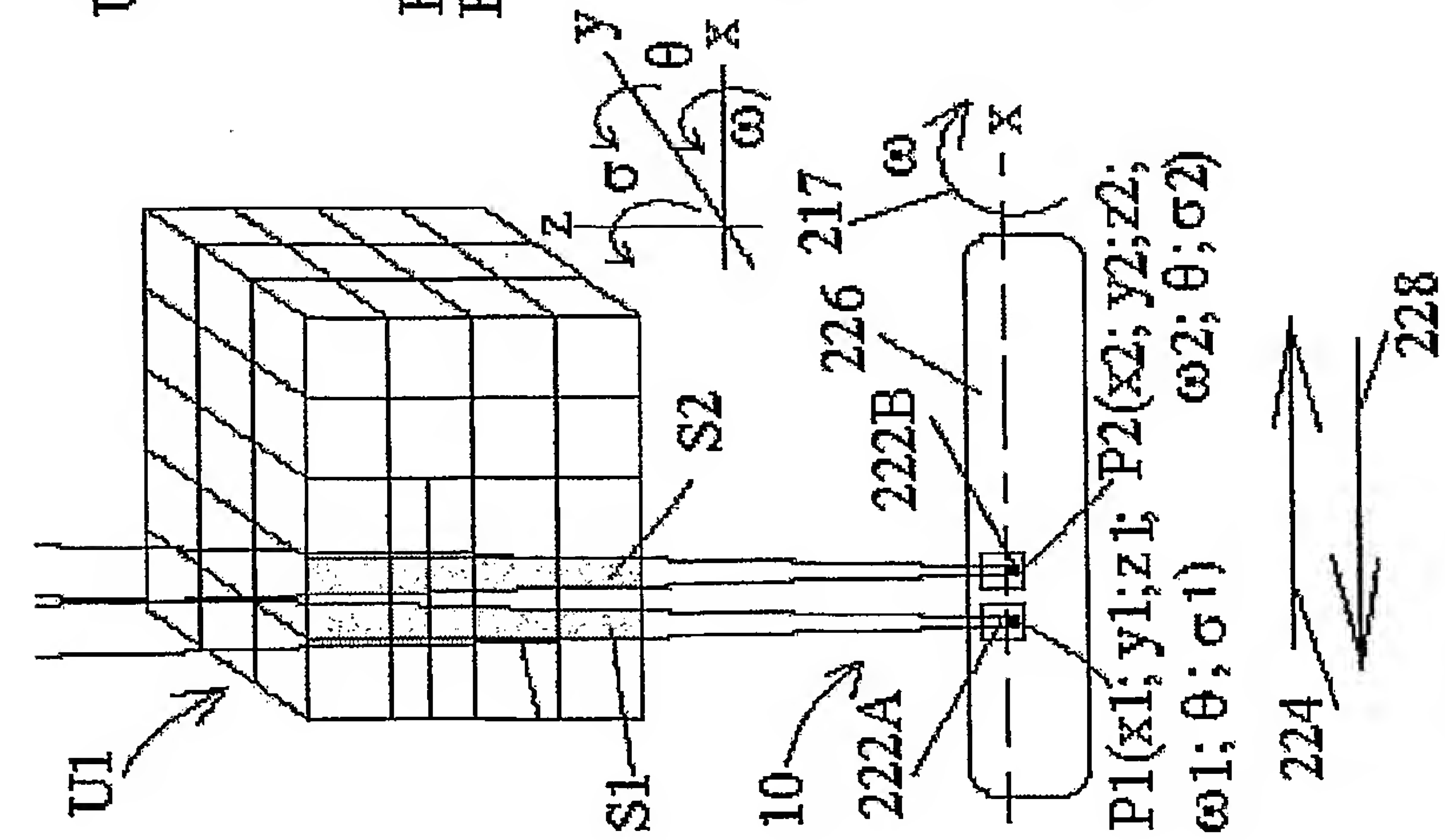


Figure 13A

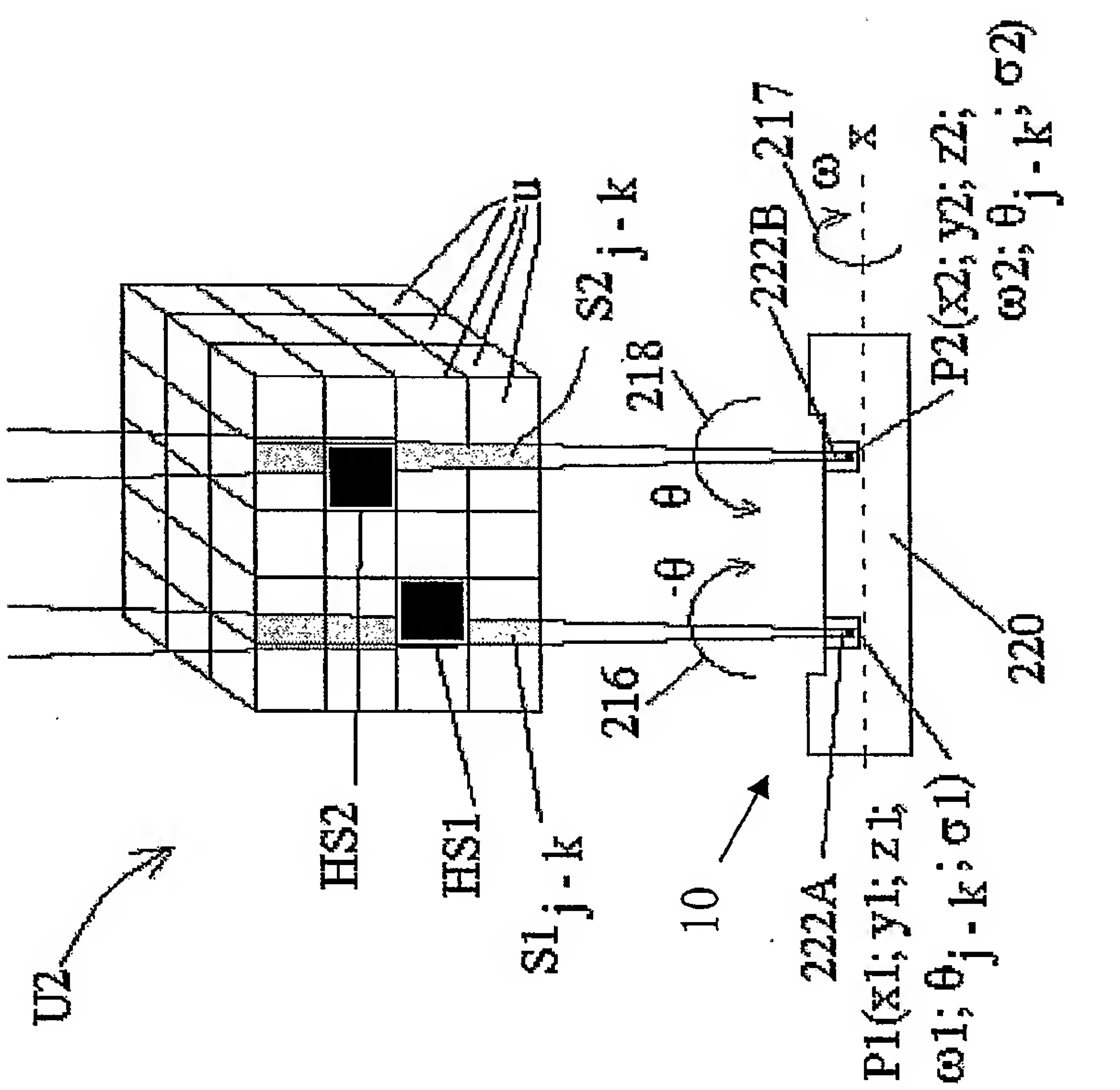


Figure 13D

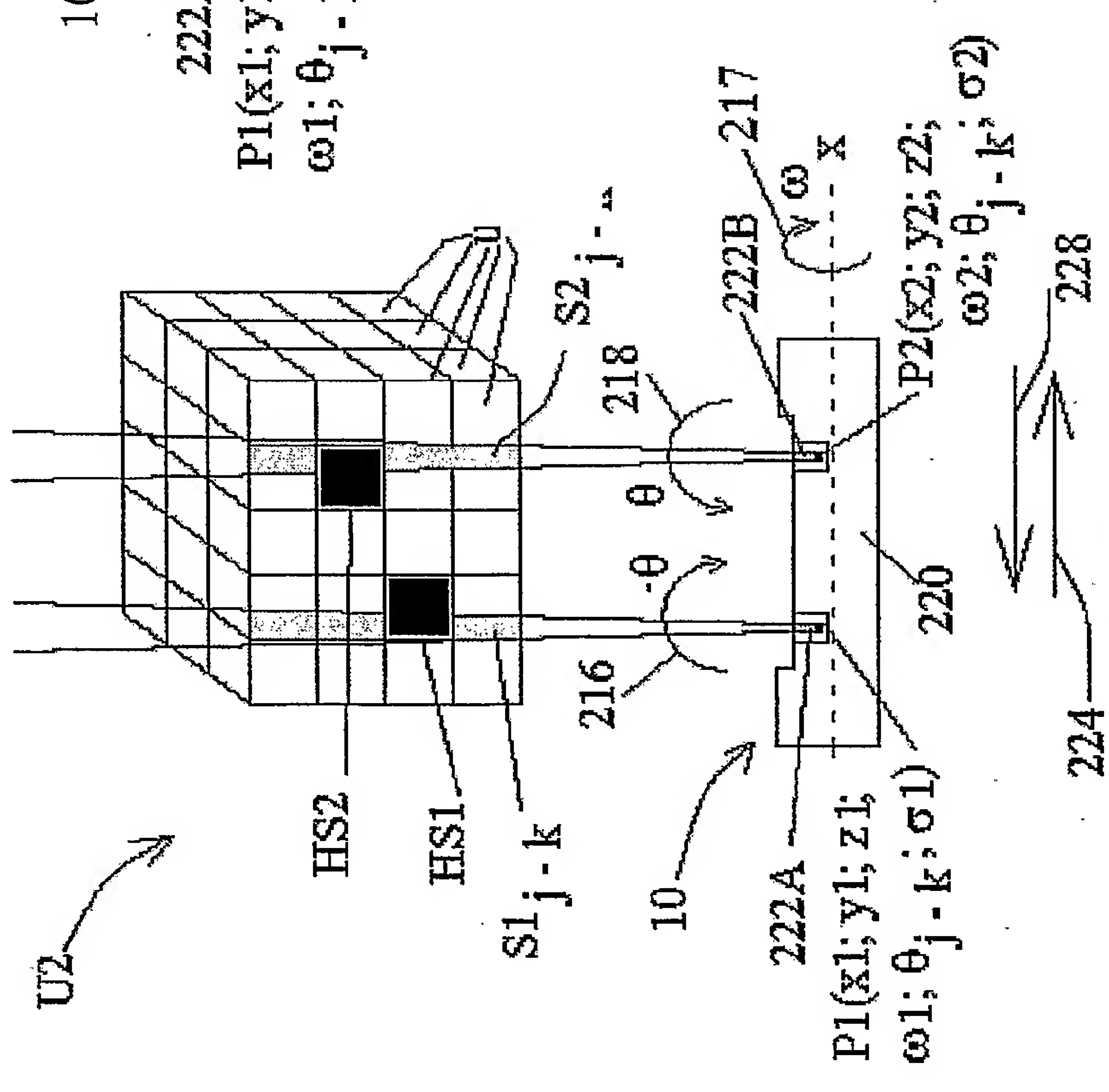


Figure 13E

Figure 14

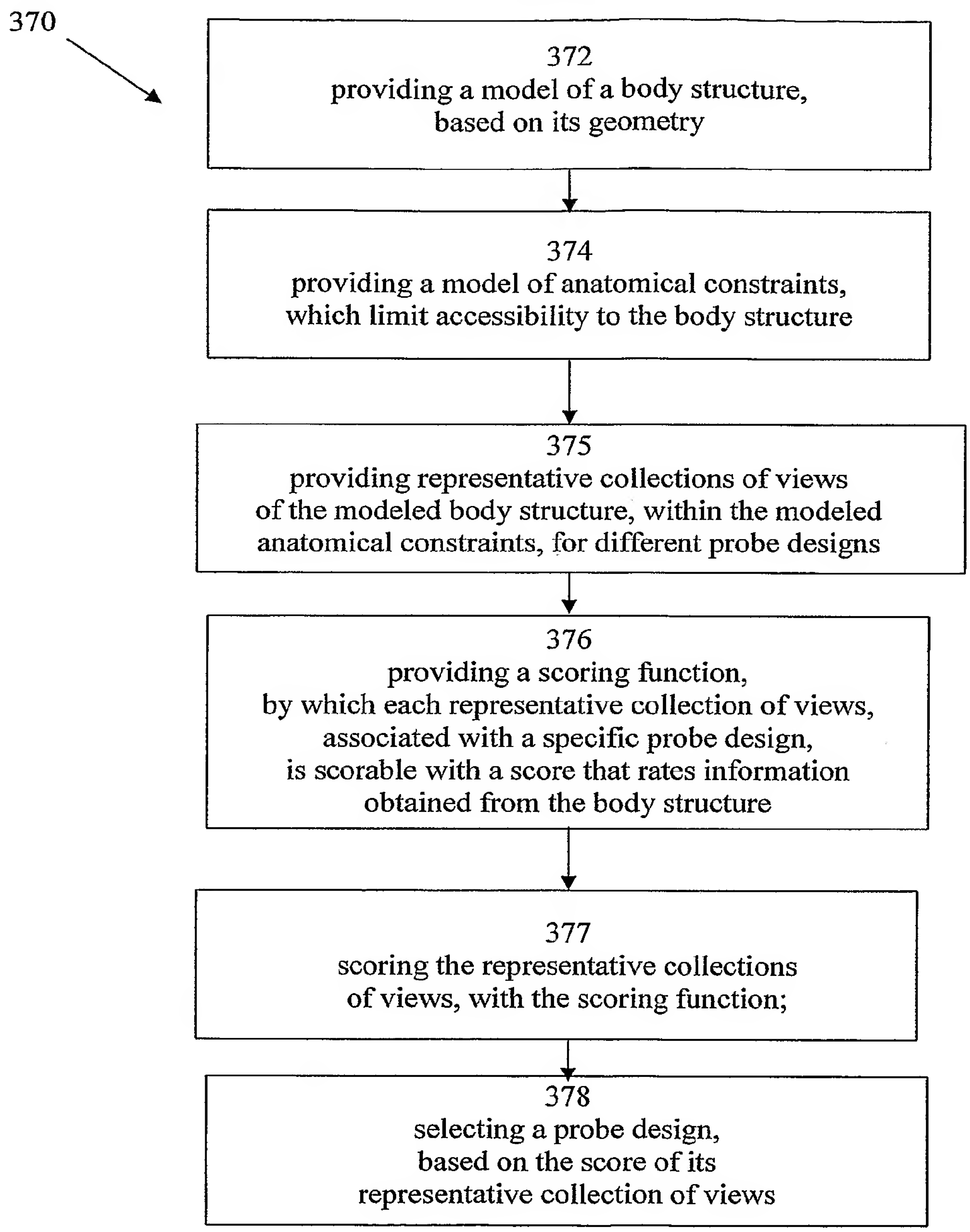

370
372
providing a model of a body structure,
based on its geometry
374
providing a model of anatomical constraints,
which limit accessibility to the body structure
375
providing representative collections of views
of the modeled body structure, within the modeled
anatomical constraints, for different probe designs
376
providing a scoring function,
by which each representative collection of views,
associated with a specific probe design,
is scorable with a score that rates information
obtained from the body structure
377
scoring the representative collections
of views, with the scoring function;
378
selecting a probe design,
based on the score of its
representative collection of views

Figure 15

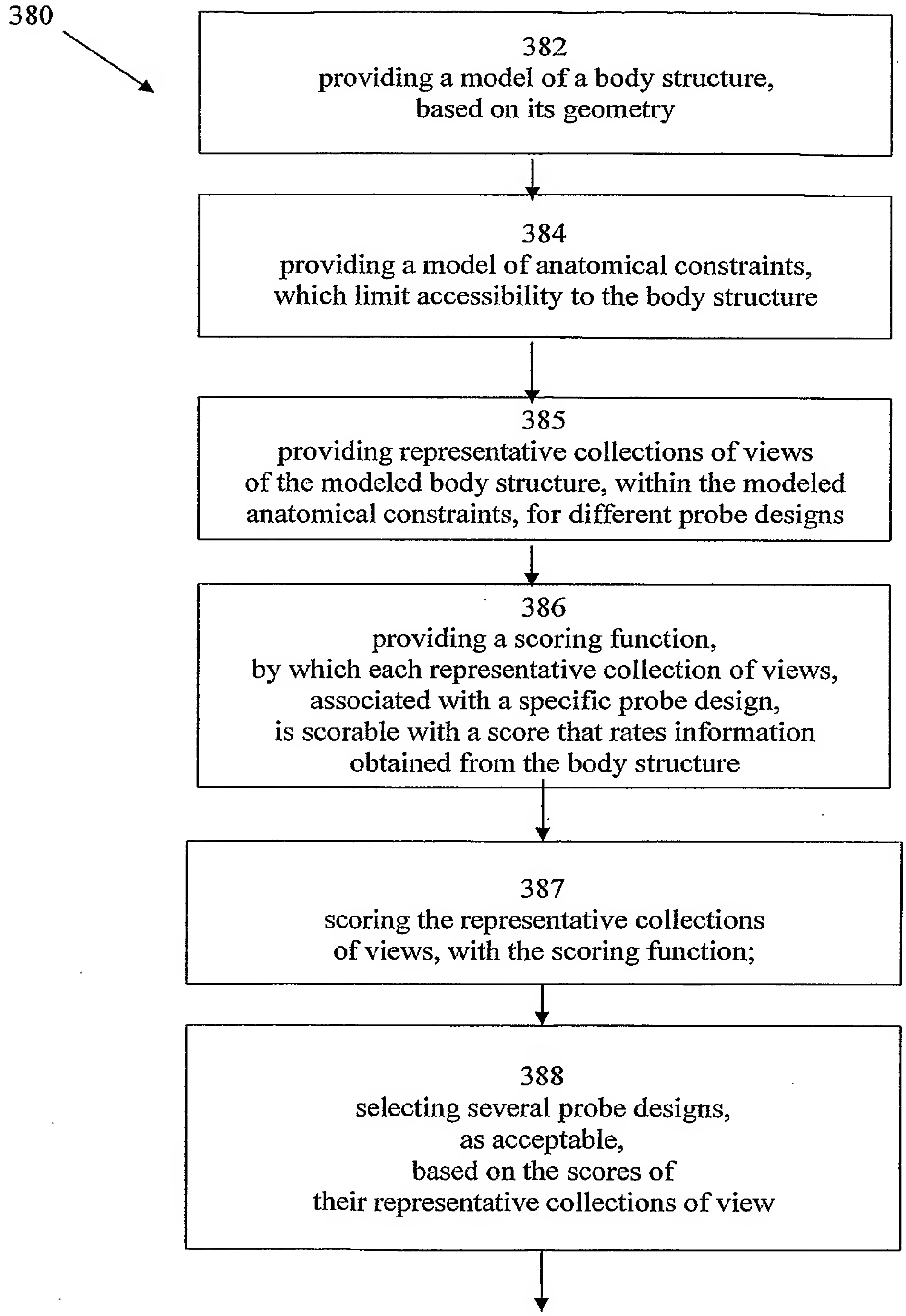
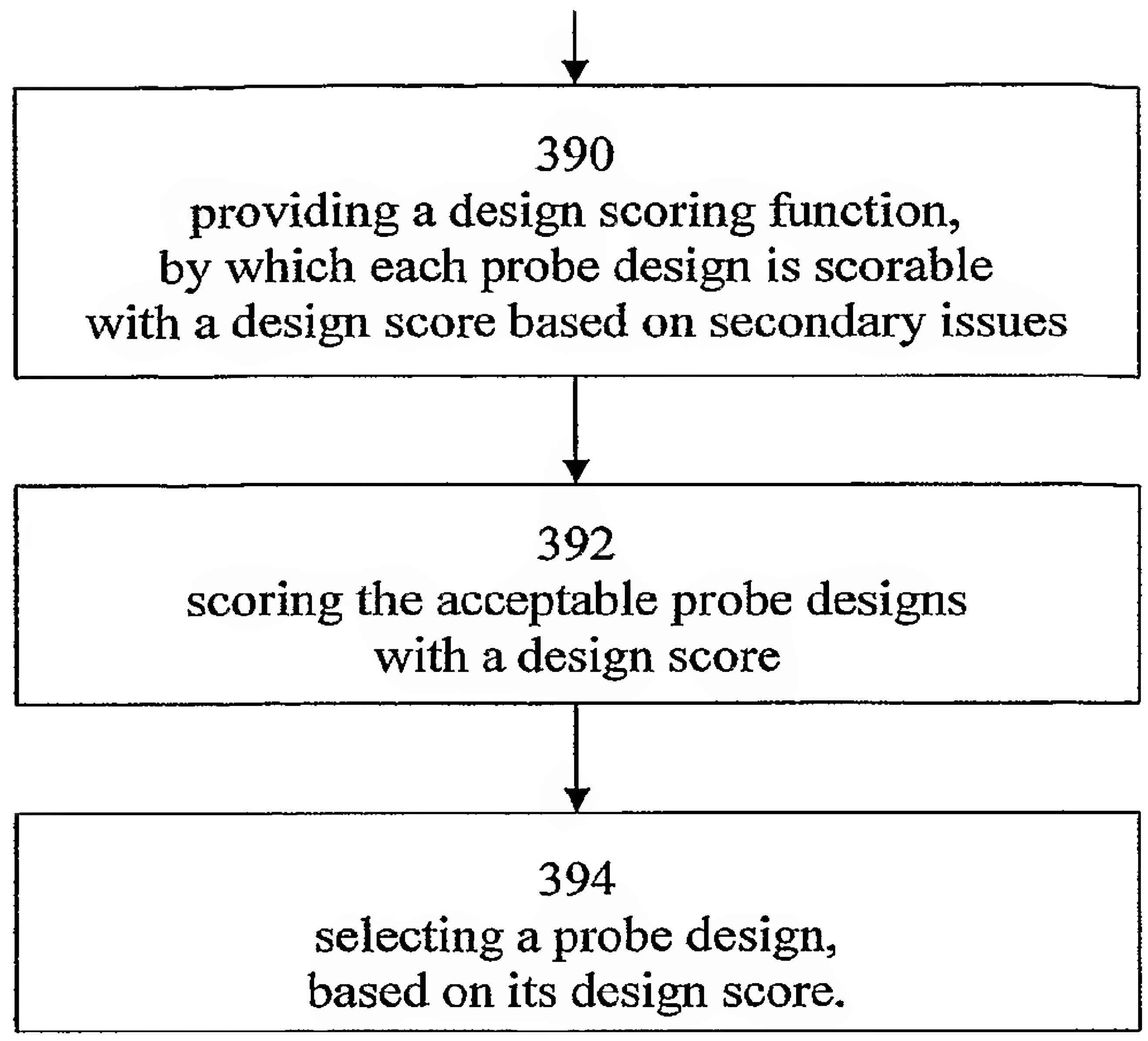

380
382
providing a model of a body structure,
based on its geometry
384
providing a model of anatomical constraints,
which limit accessibility to the body structure
385
providing representative collections of views
of the modeled body structure, within the modeled
anatomical constraints, for different probe designs
386
providing a scoring function,
by which each representative collection of views,
associated with a specific probe design,
is scorable with a score that rates information
obtained from the body structure
387
scoring the representative collections
of views, with the scoring function;
388
selecting several probe designs,
as acceptable,
based on the scores of
their representative collections of view

Figure 15 (continued)



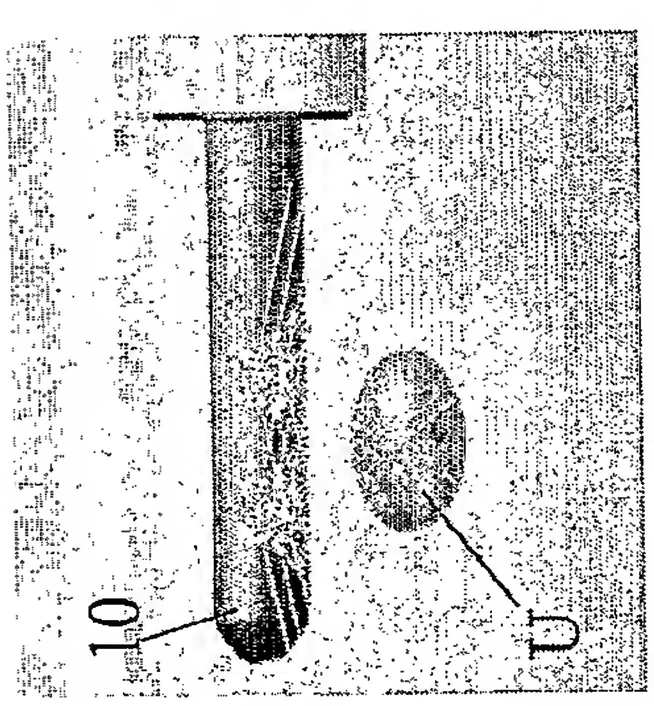


Figure 16A

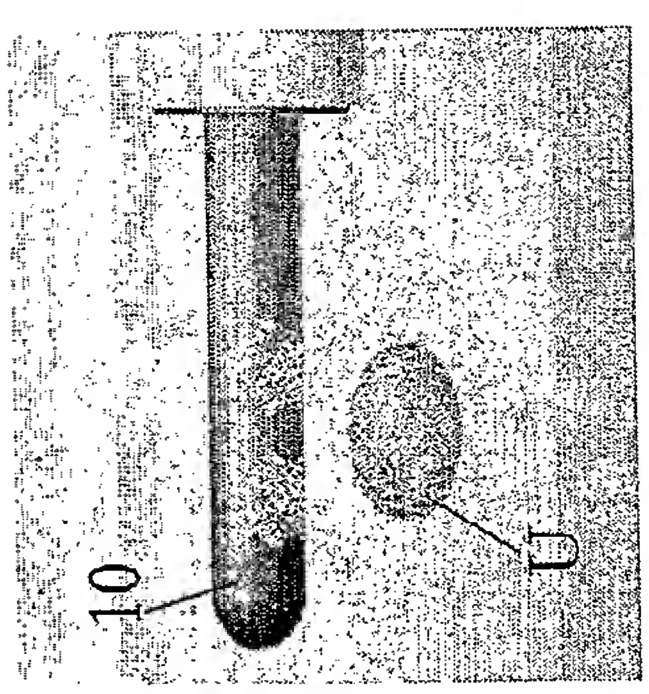


Figure 16B

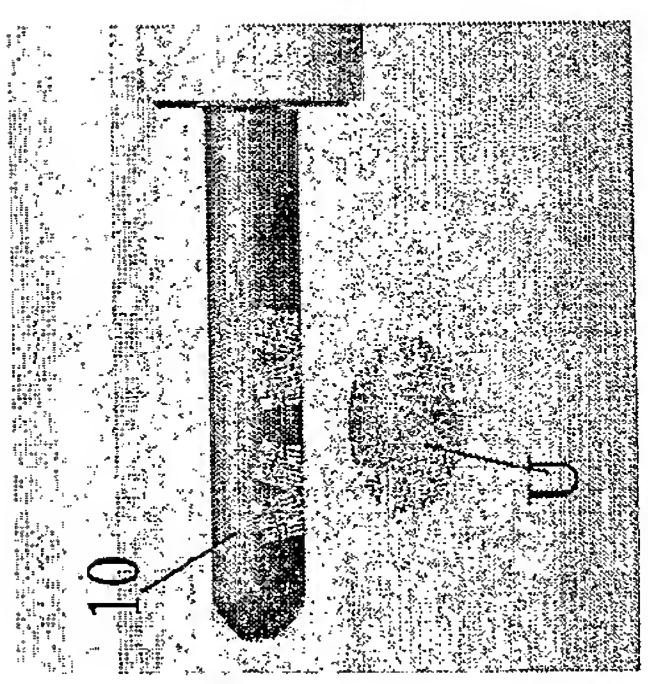


Figure 16C

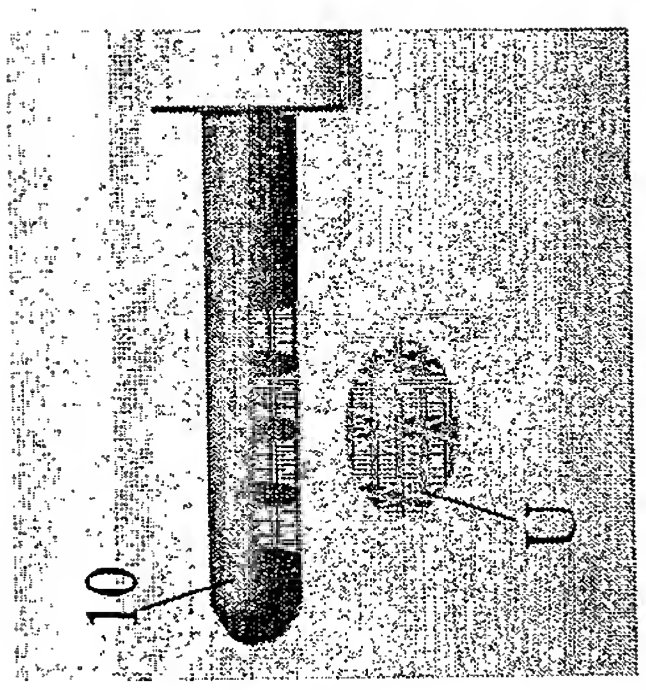


Figure 16D

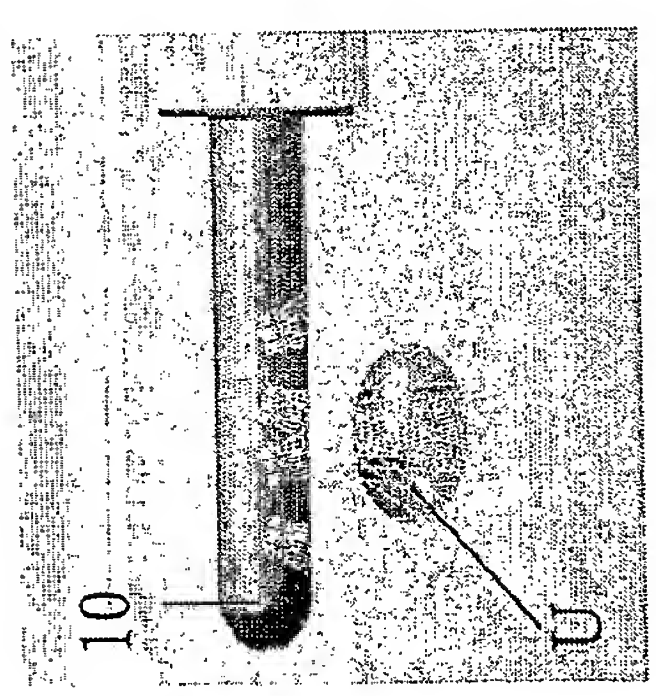


Figure 16E

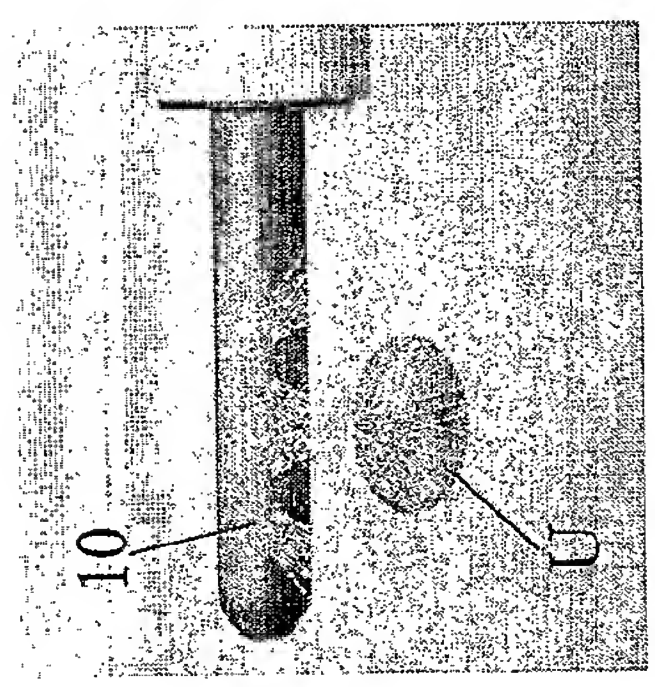


Figure 16F

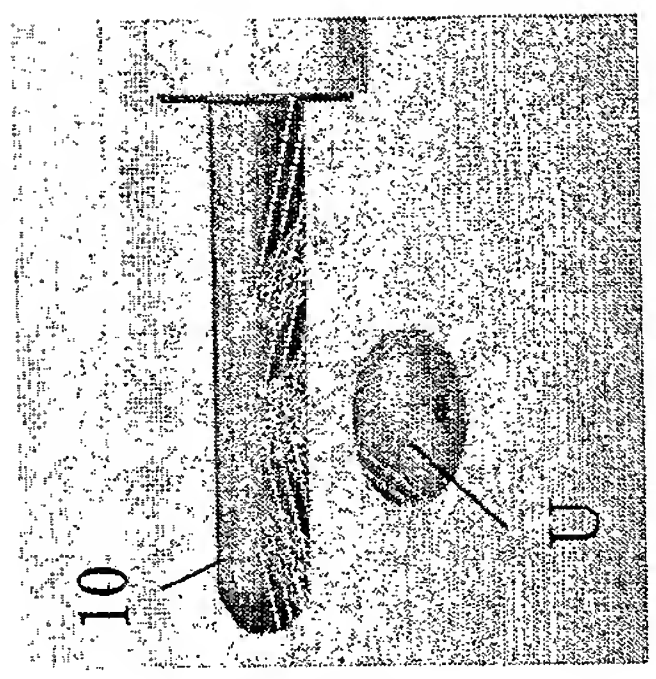


Figure 16G

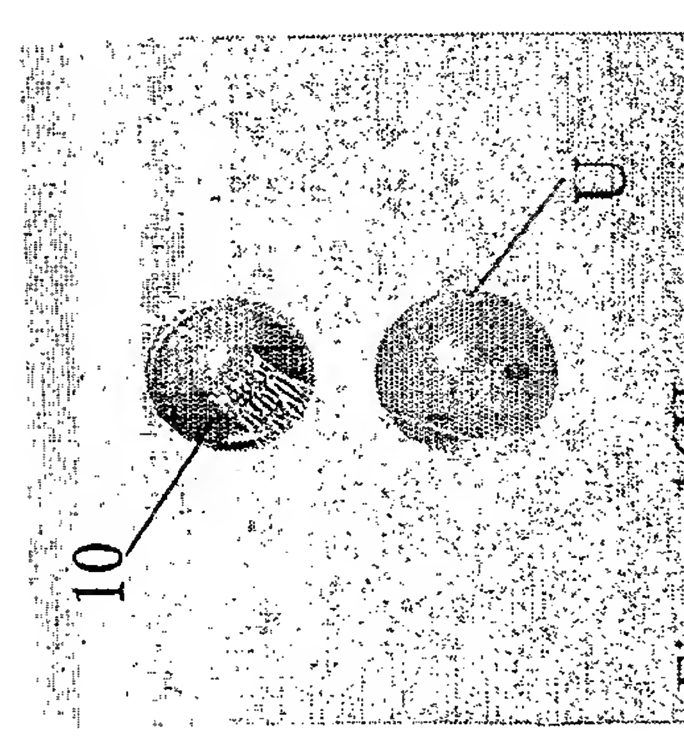


Figure 16H

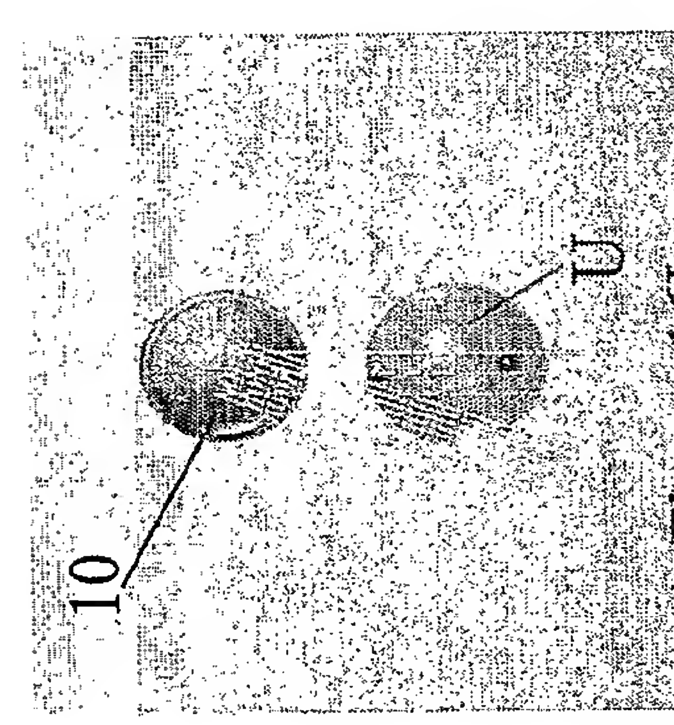


Figure 16I

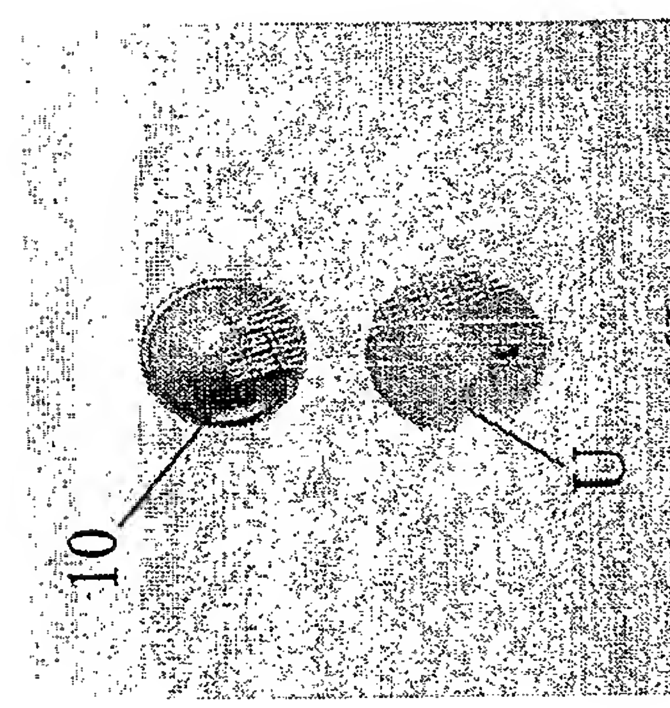


Figure 16J

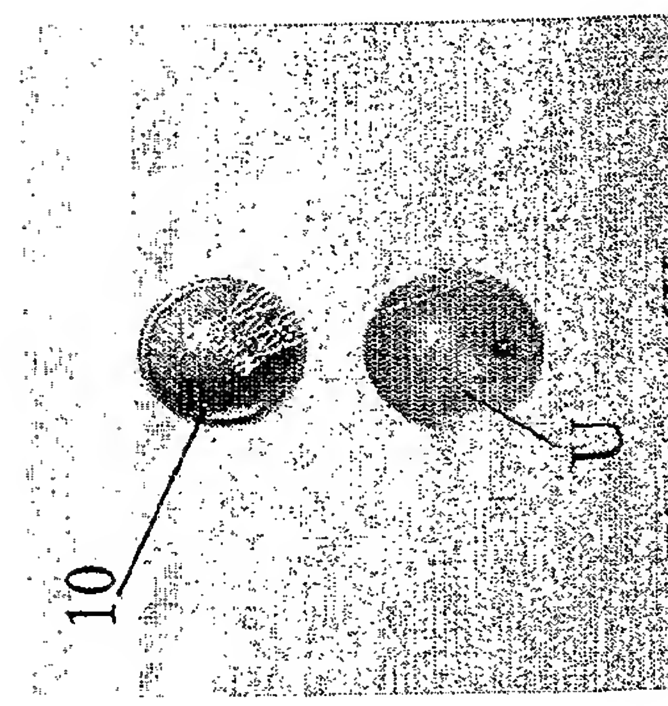


Figure 16K

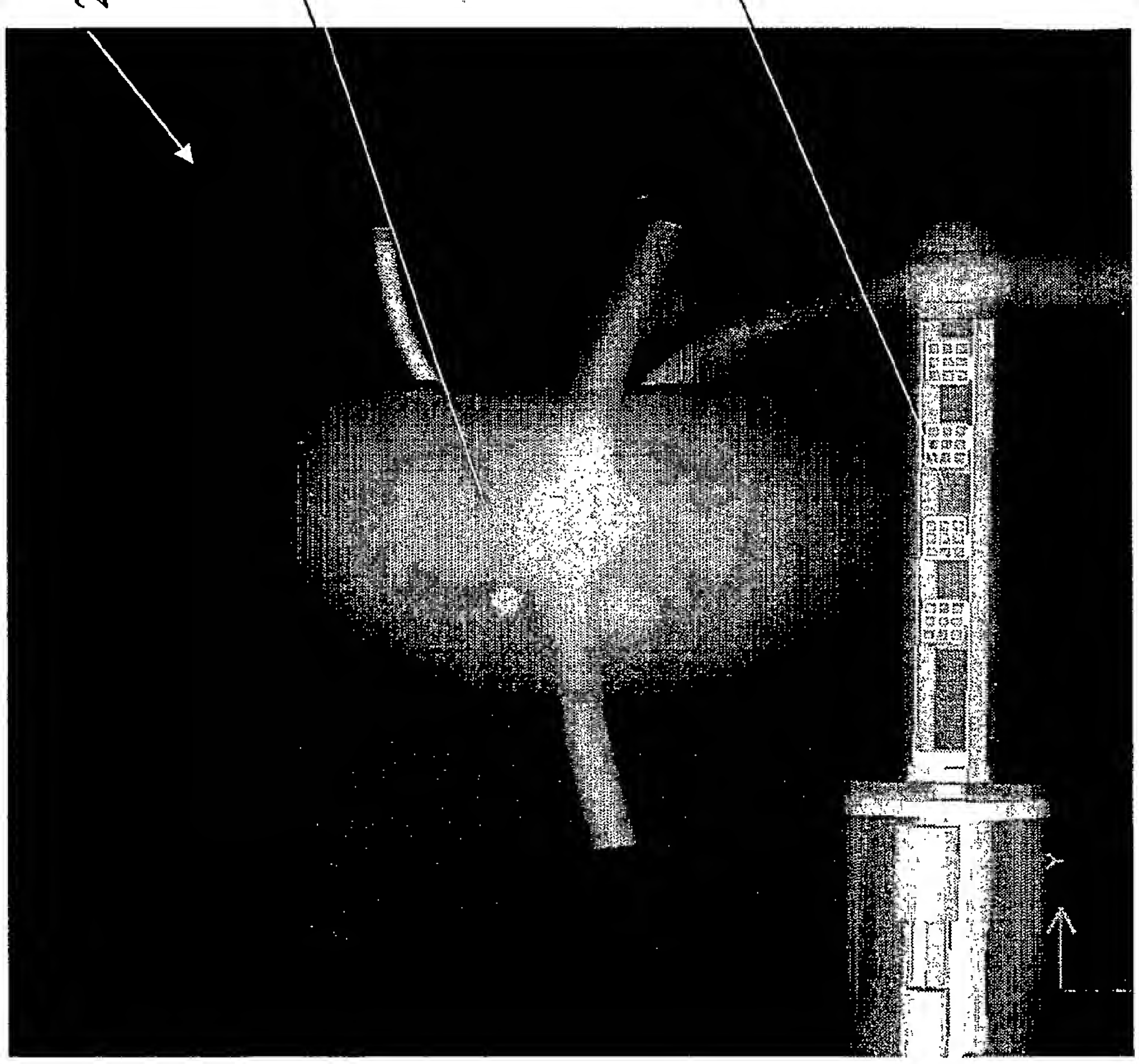
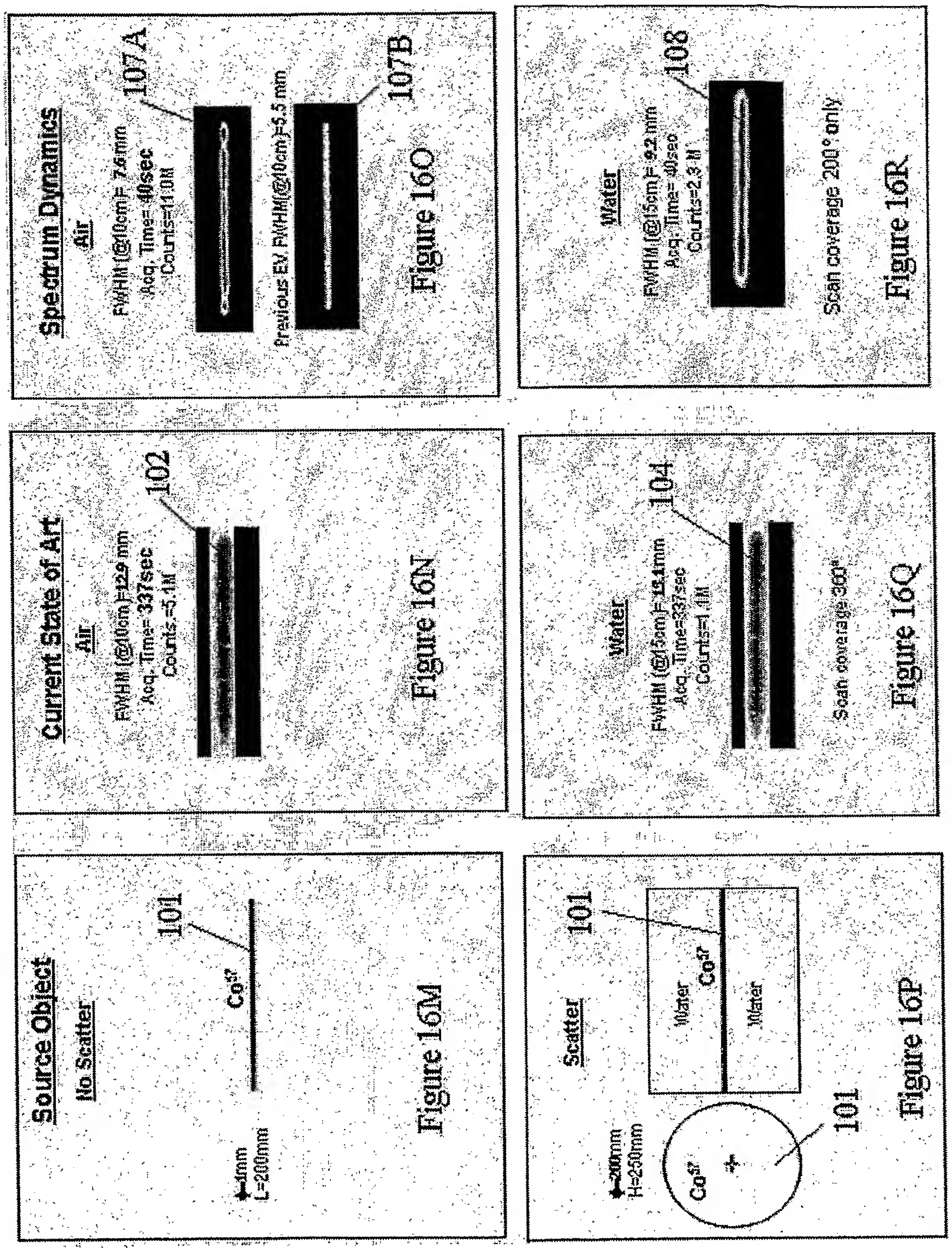


Figure 16L


Source Object
No Scatter
Co57
101
L=200mm
Figure 16M
Current State of Art
Air
FWHM(@10cm)=12.9 mm
Acq. Time= 337sec
Counts=5.1M
102
Figure 16N
Spectrum Dynamics
Air
FWHM(@10cm)= 7.6mm
Acq. Time= 40sec
107A
Previous EV FWHM(@10cm)=5.5 mm
107B
Figure 16O
Scatter
Water
Co57
Water
101
H=250mm
Co57
101
Figure 16P
Water
Acq. Time=337sec
Counts=1.4M
104
Scan coverage 360°
Figure 16Q
Water
FWHM(@15cm)=9.2 mm
Acq. Time=40sec
Counts=2.3 M
108
Scan coverage 200° only
Figure 16R

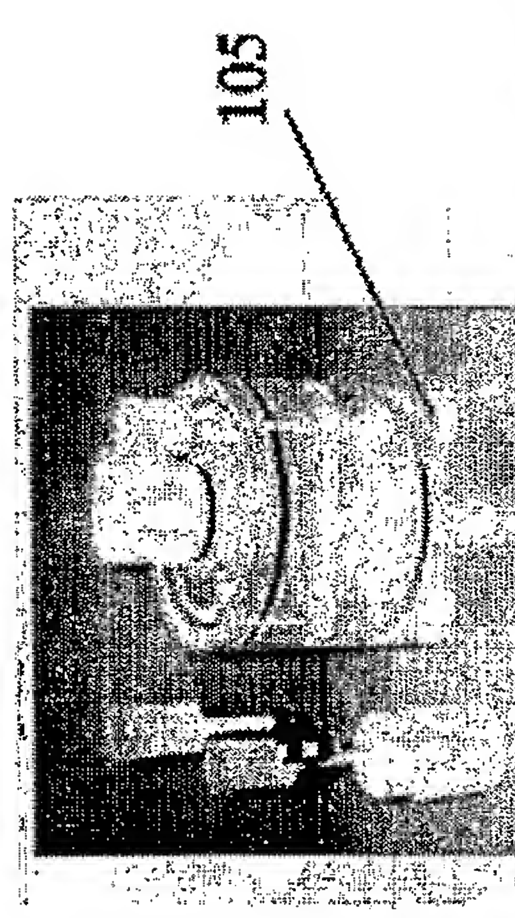


Figure 16S

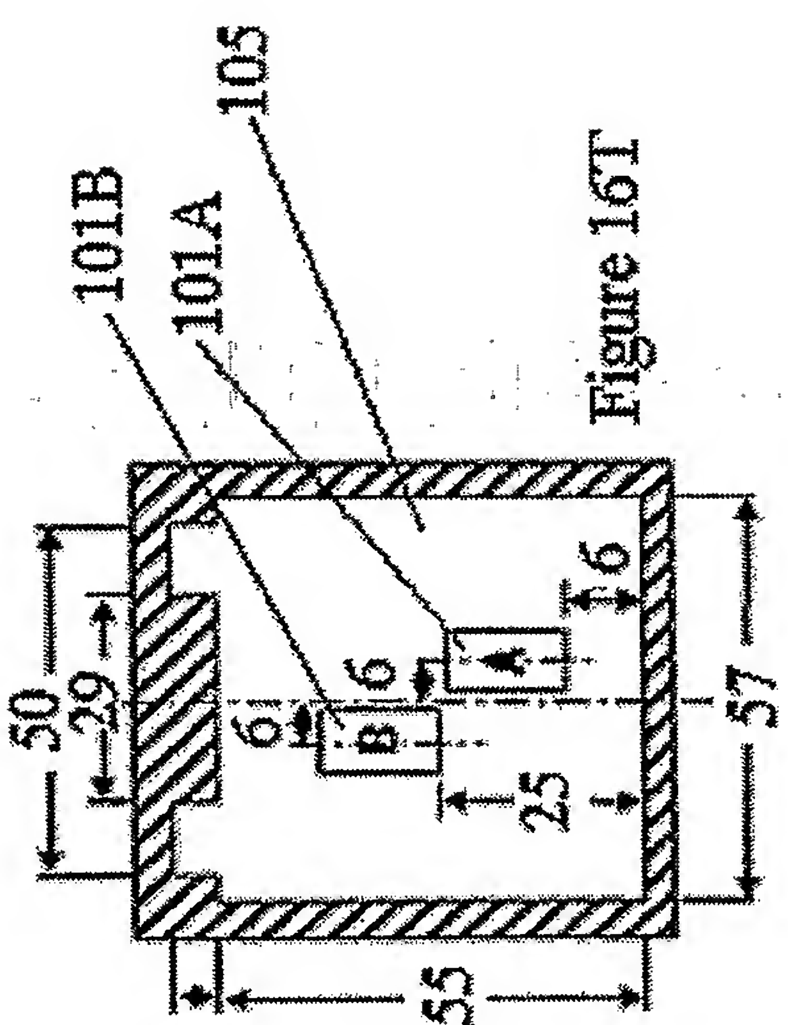


Figure 16T

Figure 16U

Spectrum-Dynamics camera

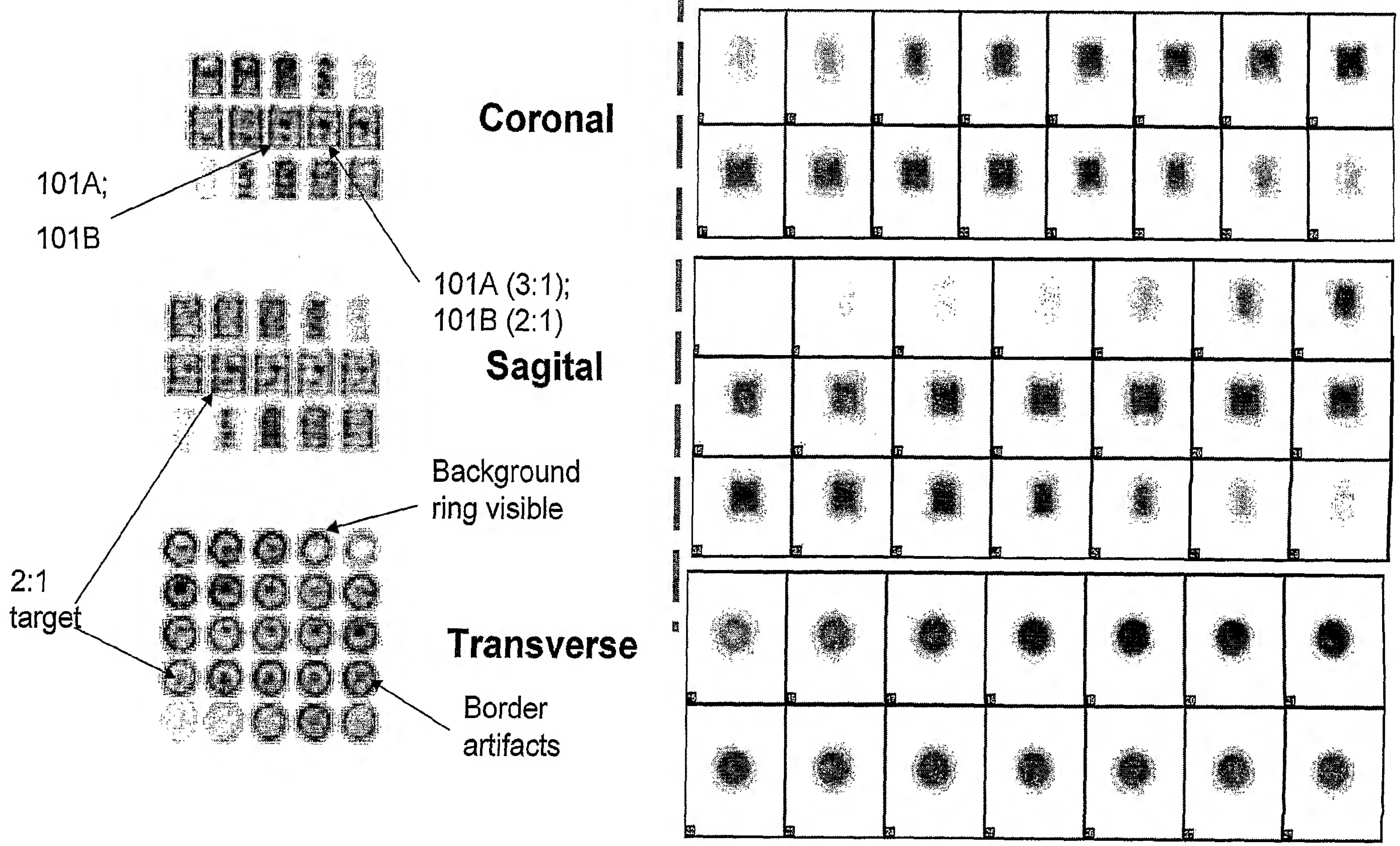
Equivalent net acquisition time: 60 sec.
positions:40, 2sec per position

Total counts: 2,500K

Millennium VG camera

Net acquisition time: 9 minutes.
Frame angle: 3°, positions:60, 9sec per position

Total counts: 2,500K



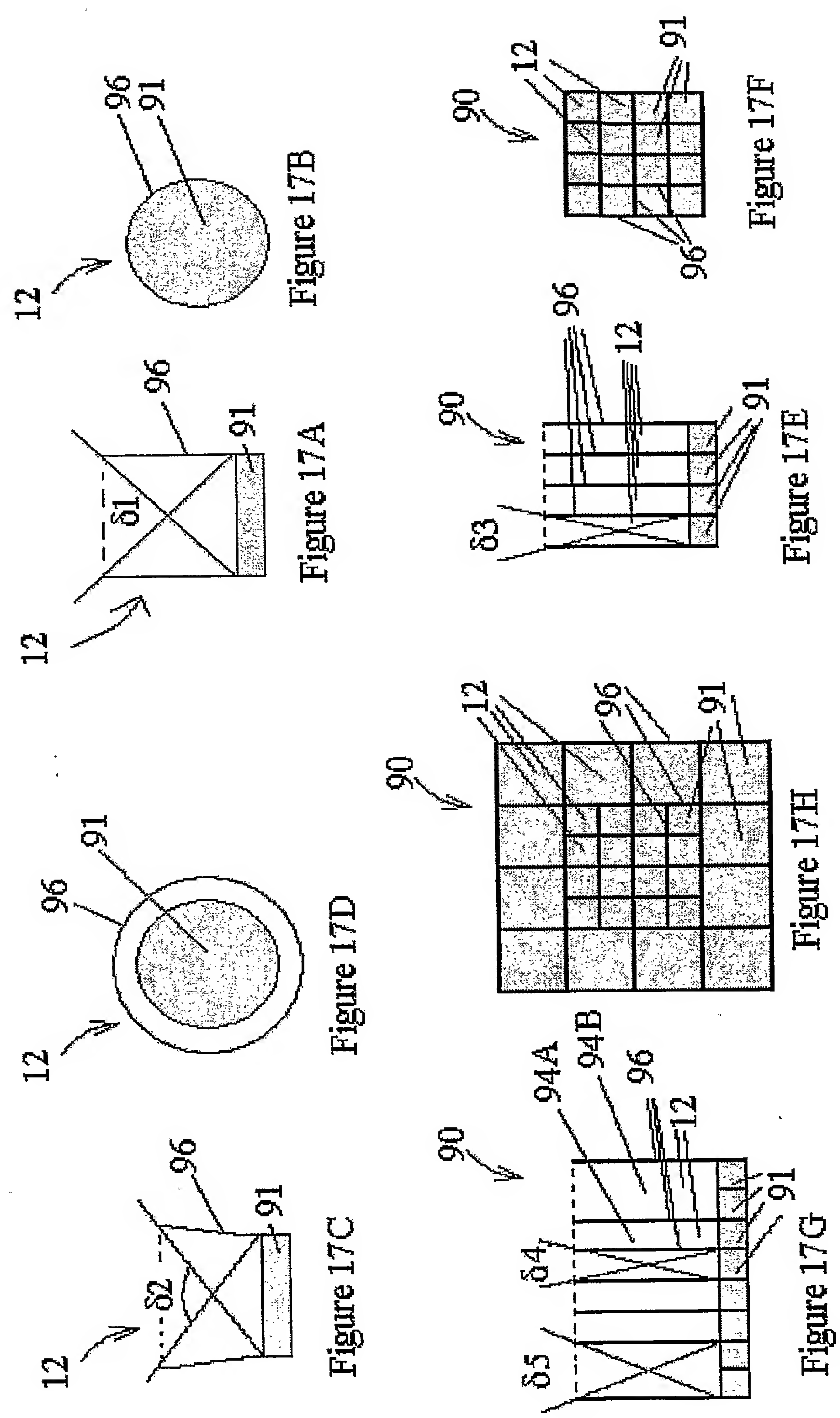


Figure 17A
Figure 17B
Figure 17C
Figure 17D
Figure 17E
Figure 17F
Figure 17G
Figure 17H

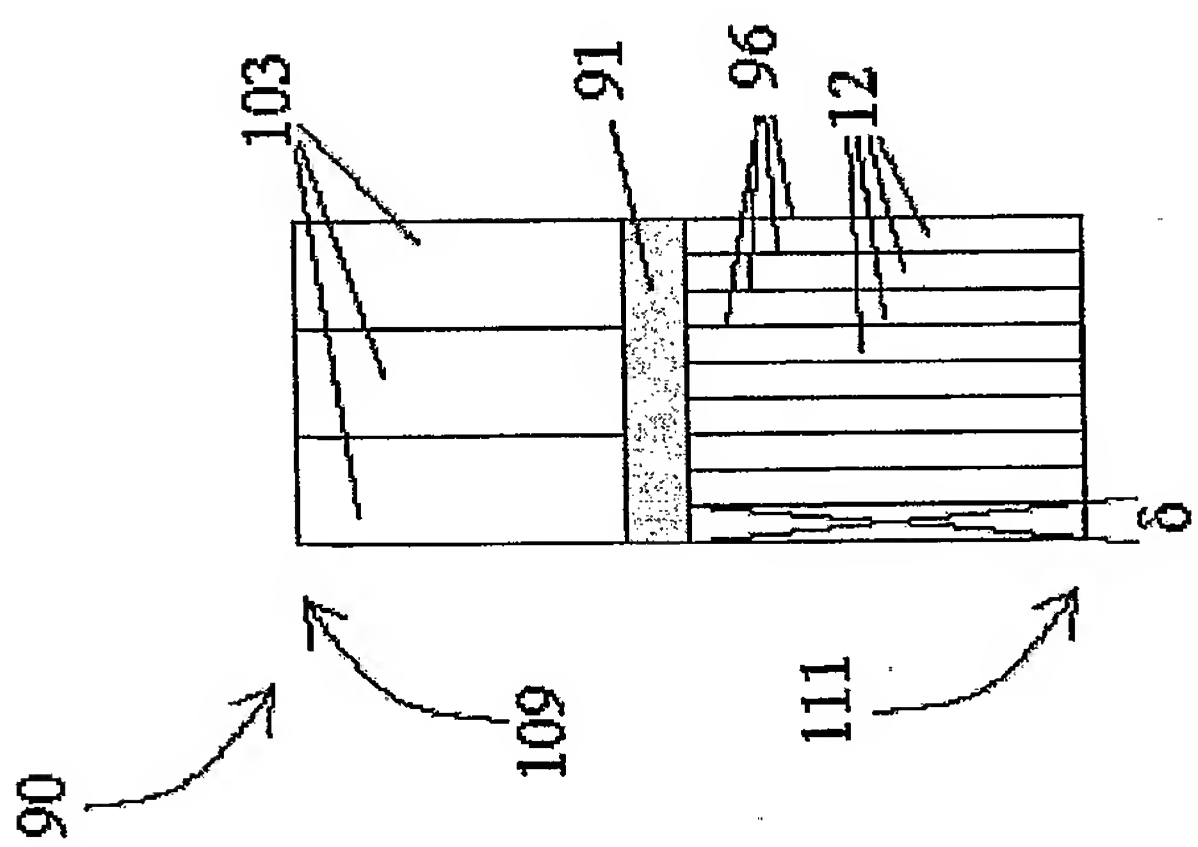


Figure 17I

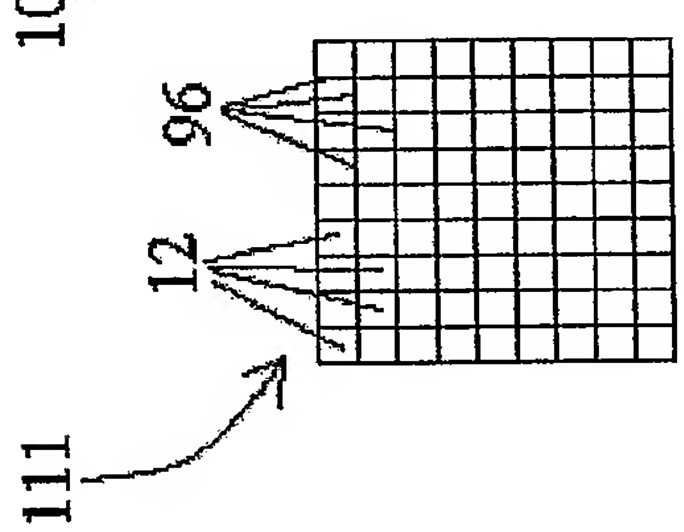


Figure 17J

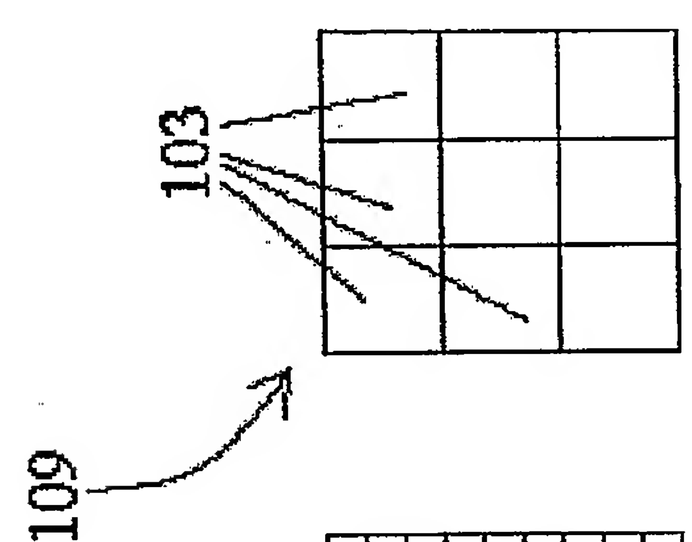


Figure 17K

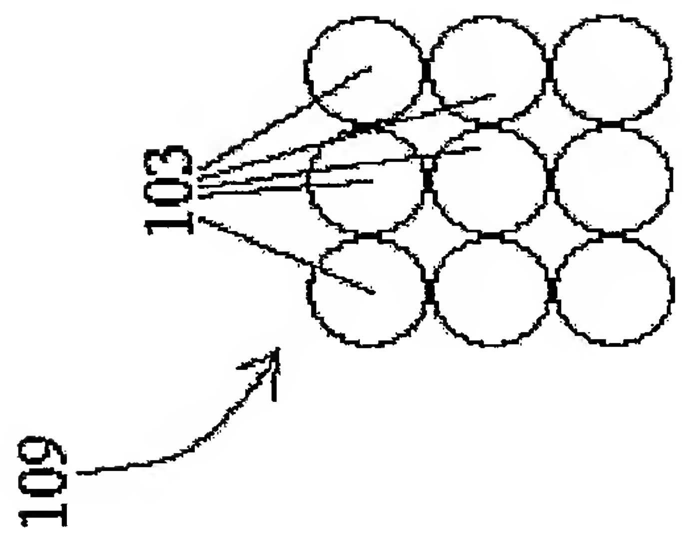


Figure 17L

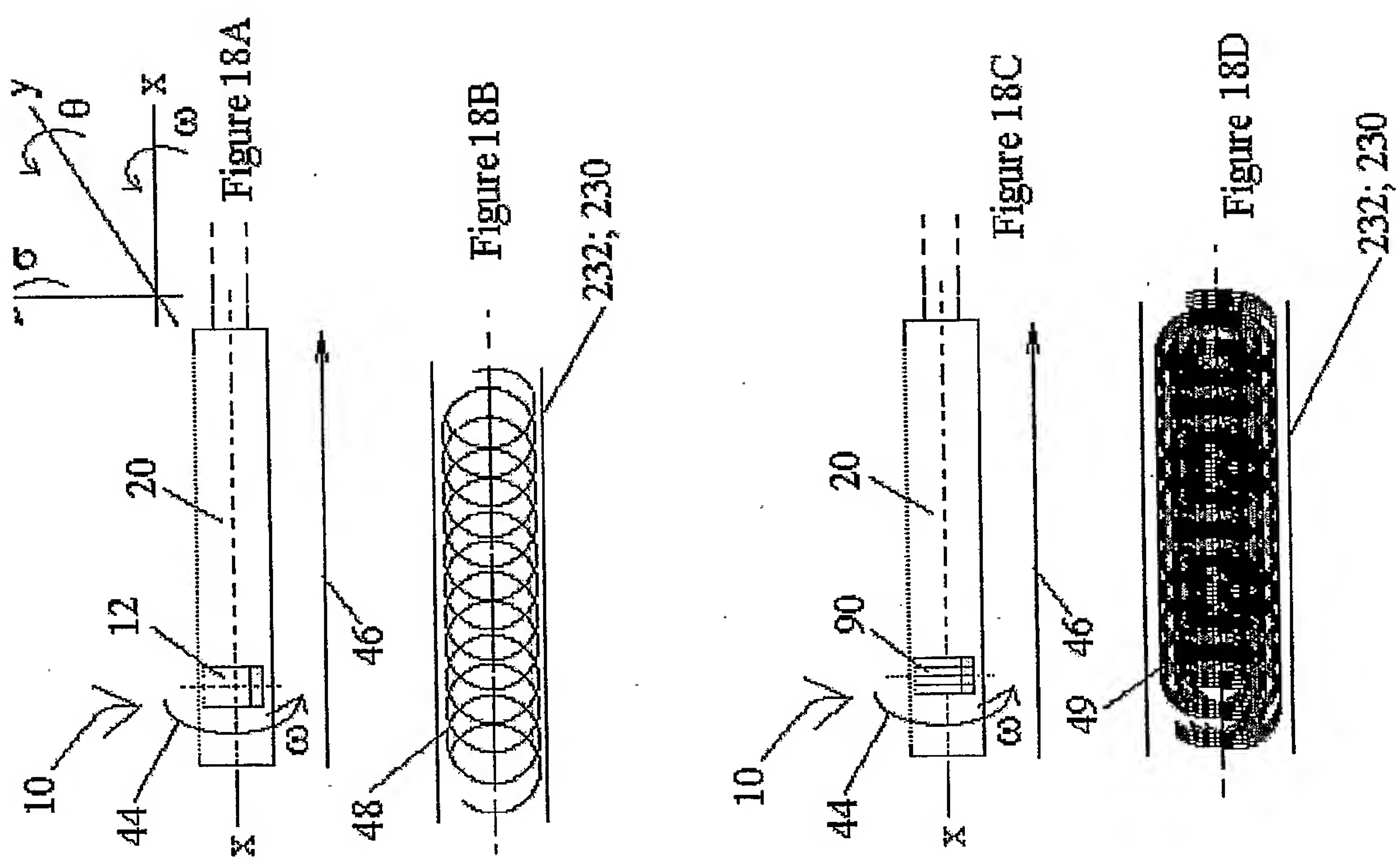


Figure 18A

Figure 18B

Figure 18C

Figure 18D

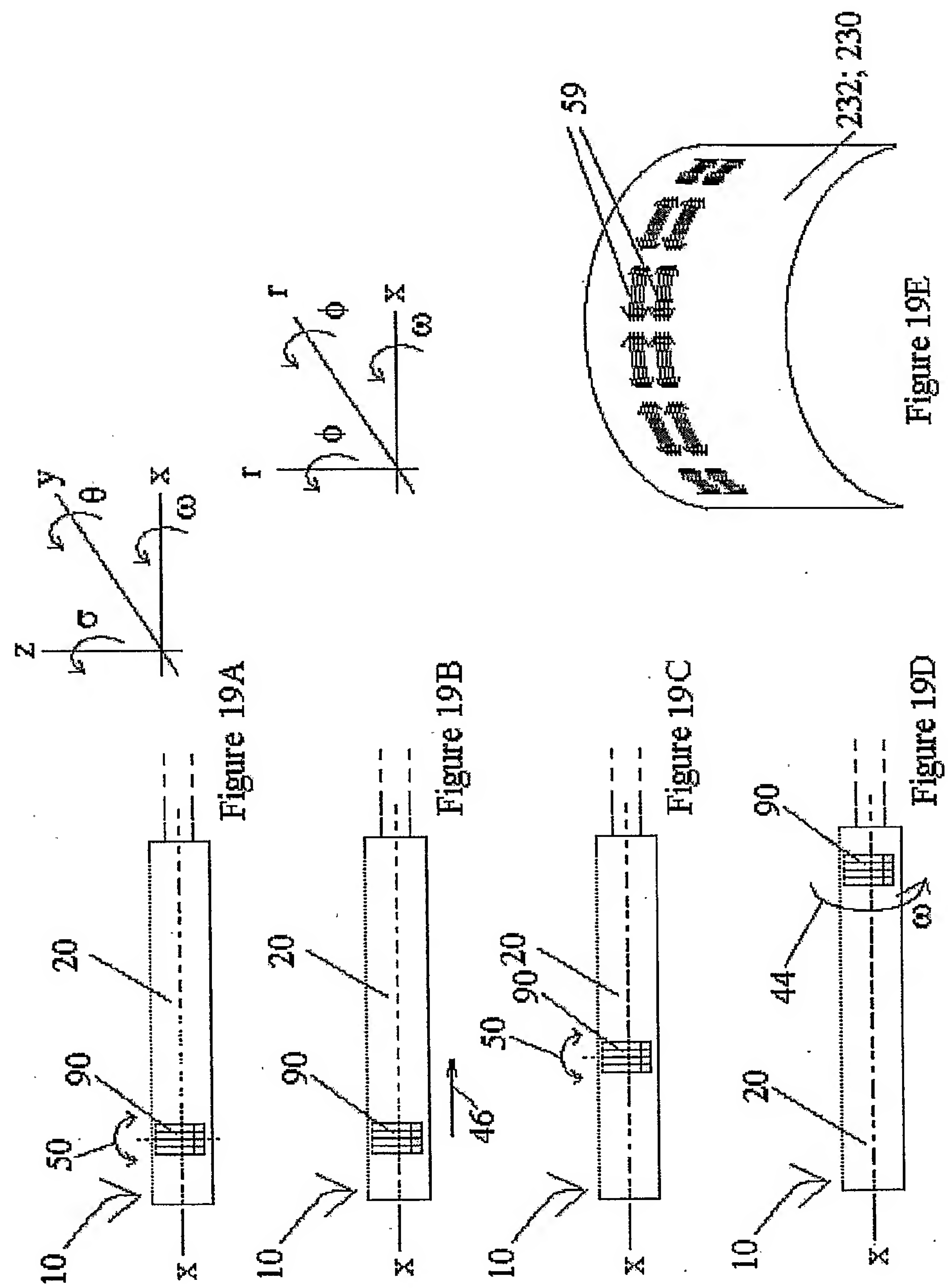


Figure 19A

Figure 19B

Figure 19C

Figure 19D

Figure 19E

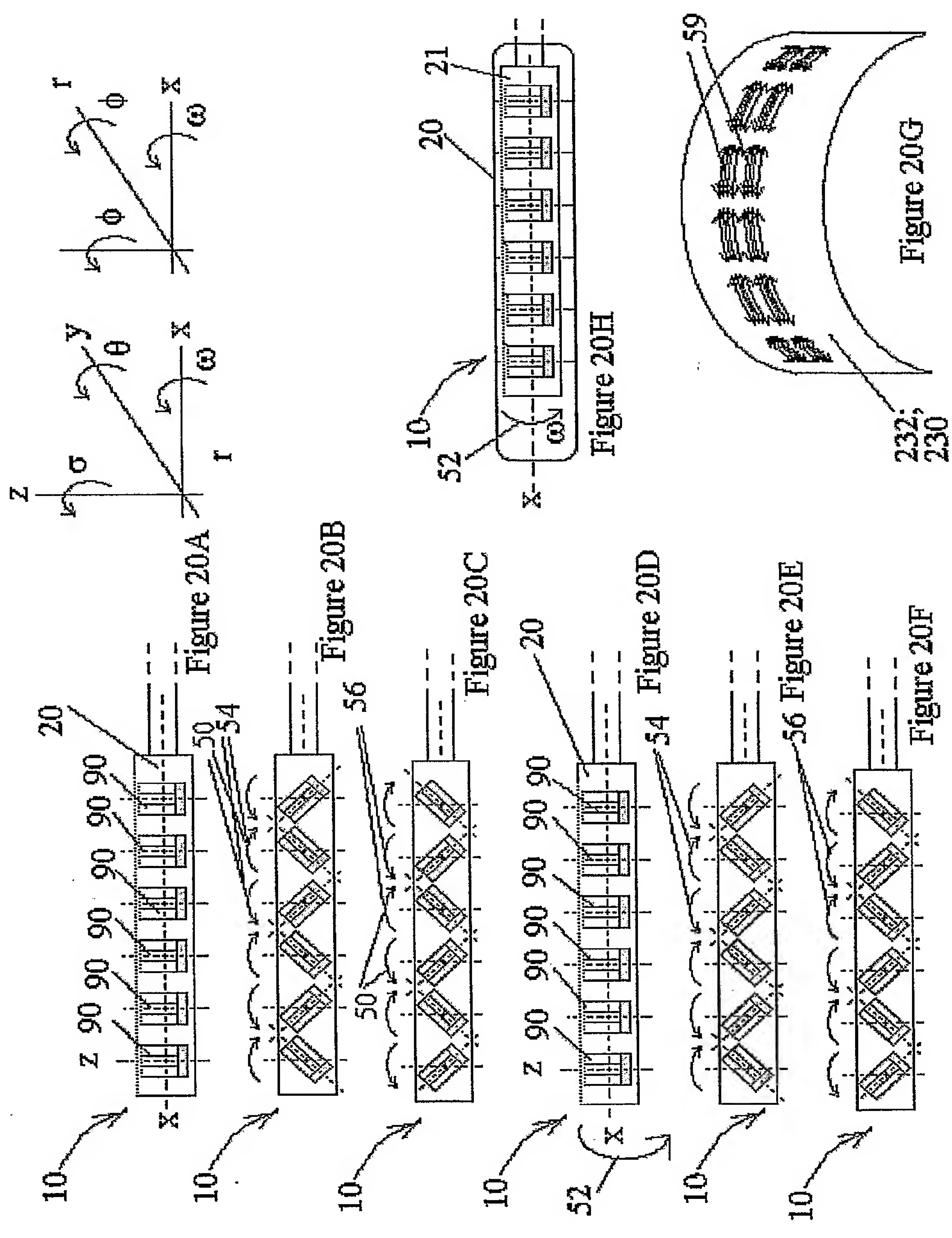


Figure 20A

Figure 20B

Figure 20C

Figure 20D

Figure 20E

Figure 20F

Figure 20G

Figure 20H

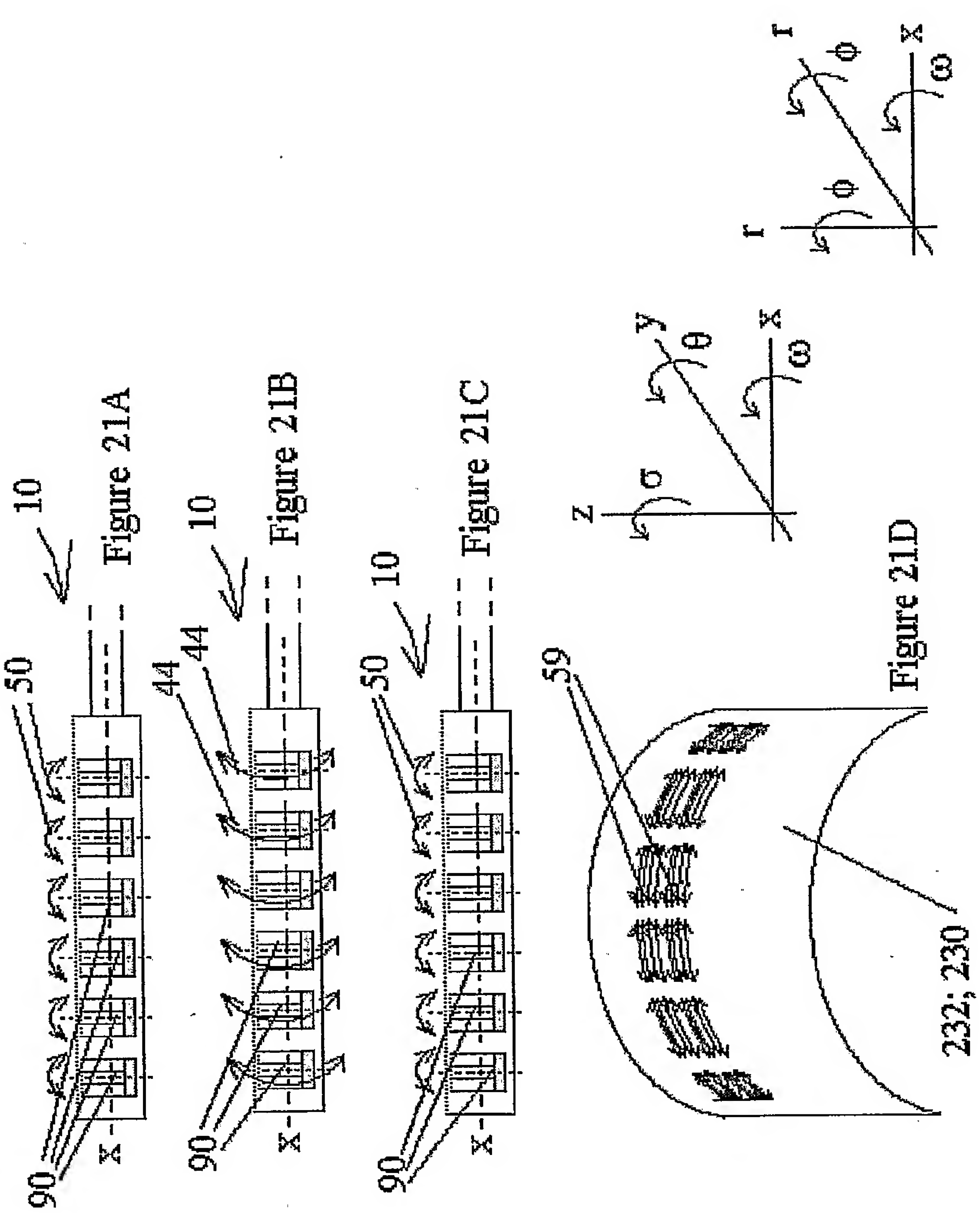


Figure 21A

Figure 21B

Figure 21C

Figure 21D

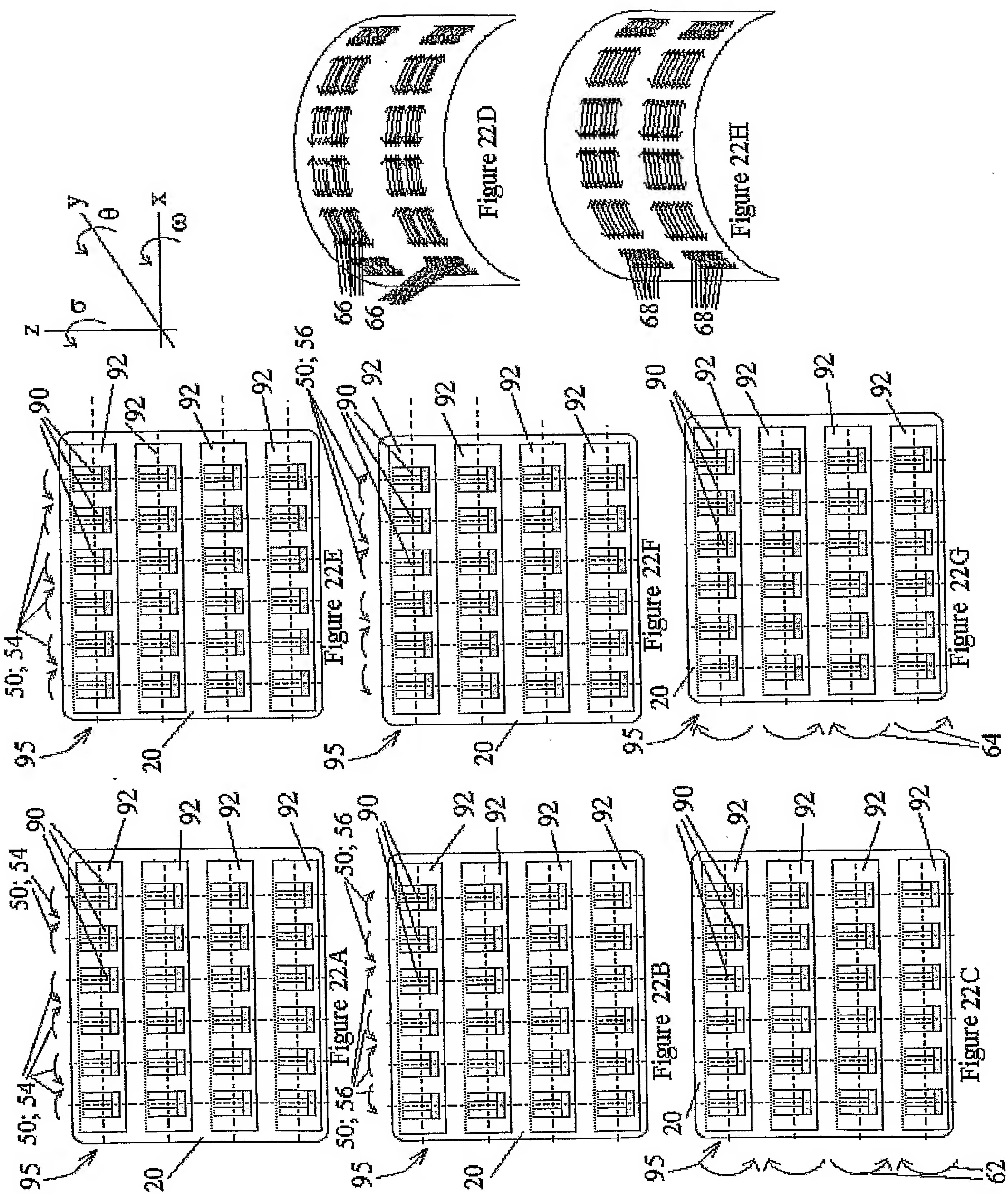


Figure 22A

Figure 22B

Figure 22C

Figure 22D

Figure 22E

Figure 22F

Figure 22G

Figure 22H

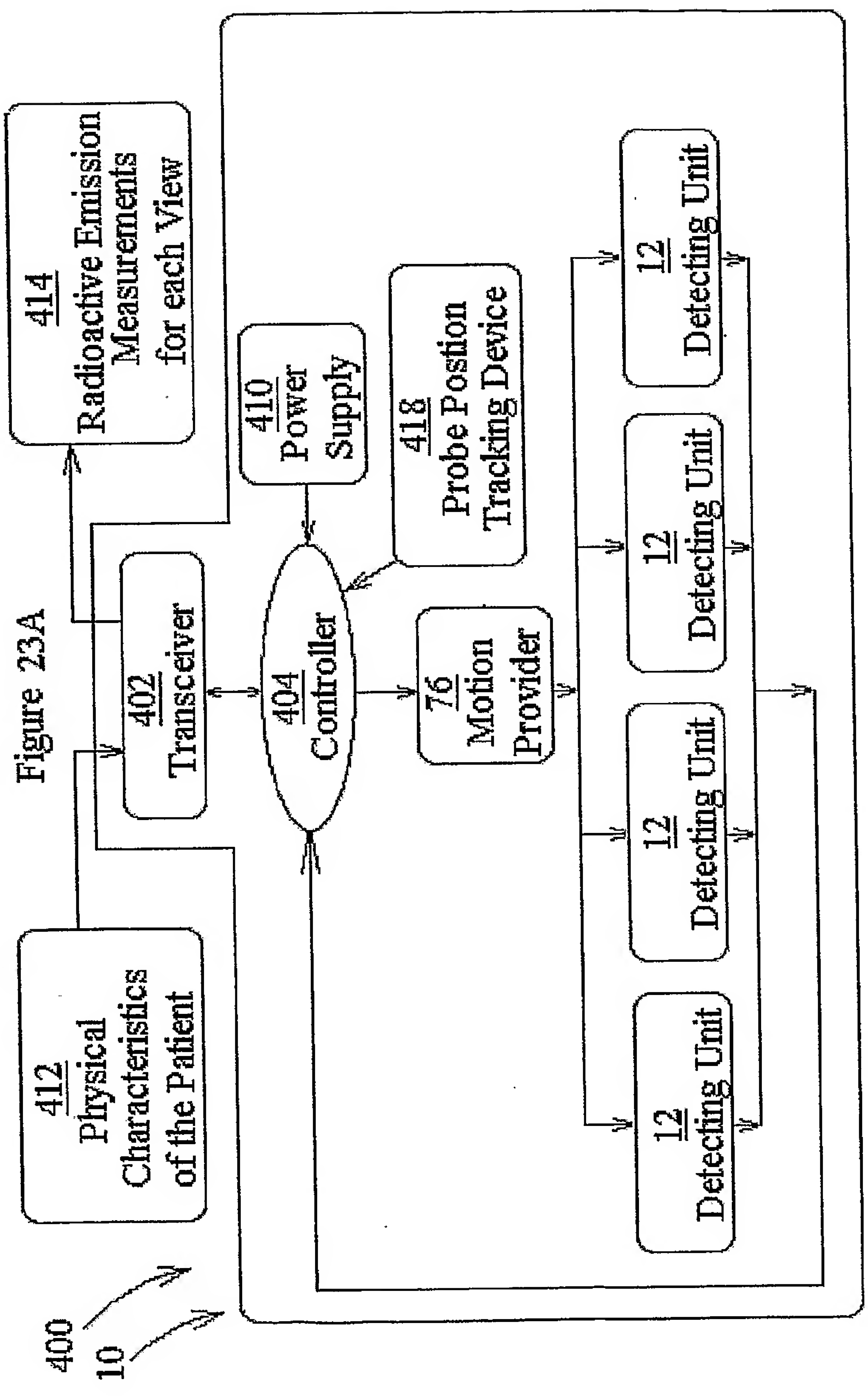

400
10
412
Physical
Characteristics
of the Patient
402
Transceiver
414
Radioactive Emission
Measurements
for each View
410
Power
Supply
404
Controller
418
Probe Postion
Tracking Device
76
Motion
Provider
12
Detecting Unit
12
Detecting Unit
12
Detecting Unit
12
Detecting Unit

Figure 23A

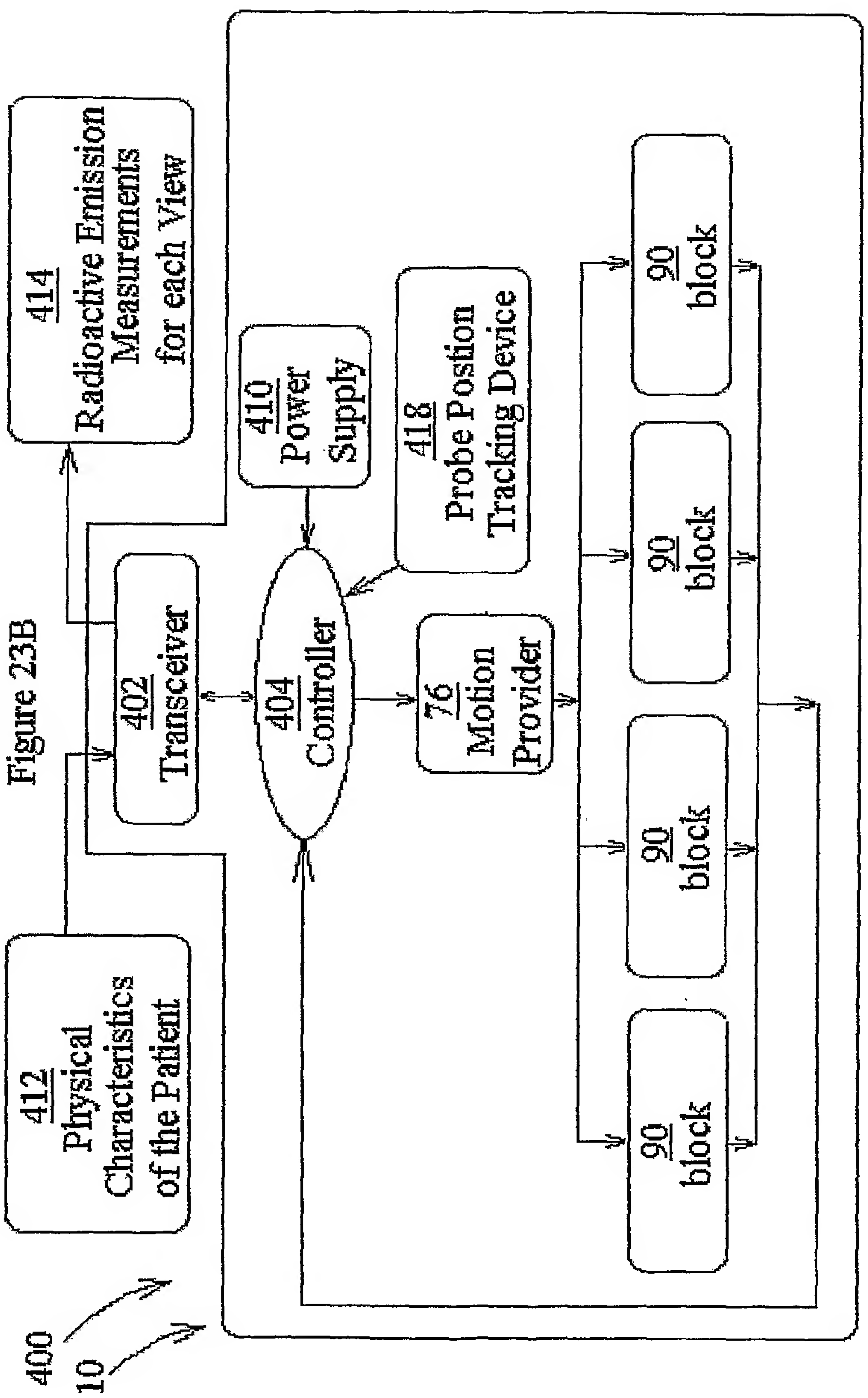
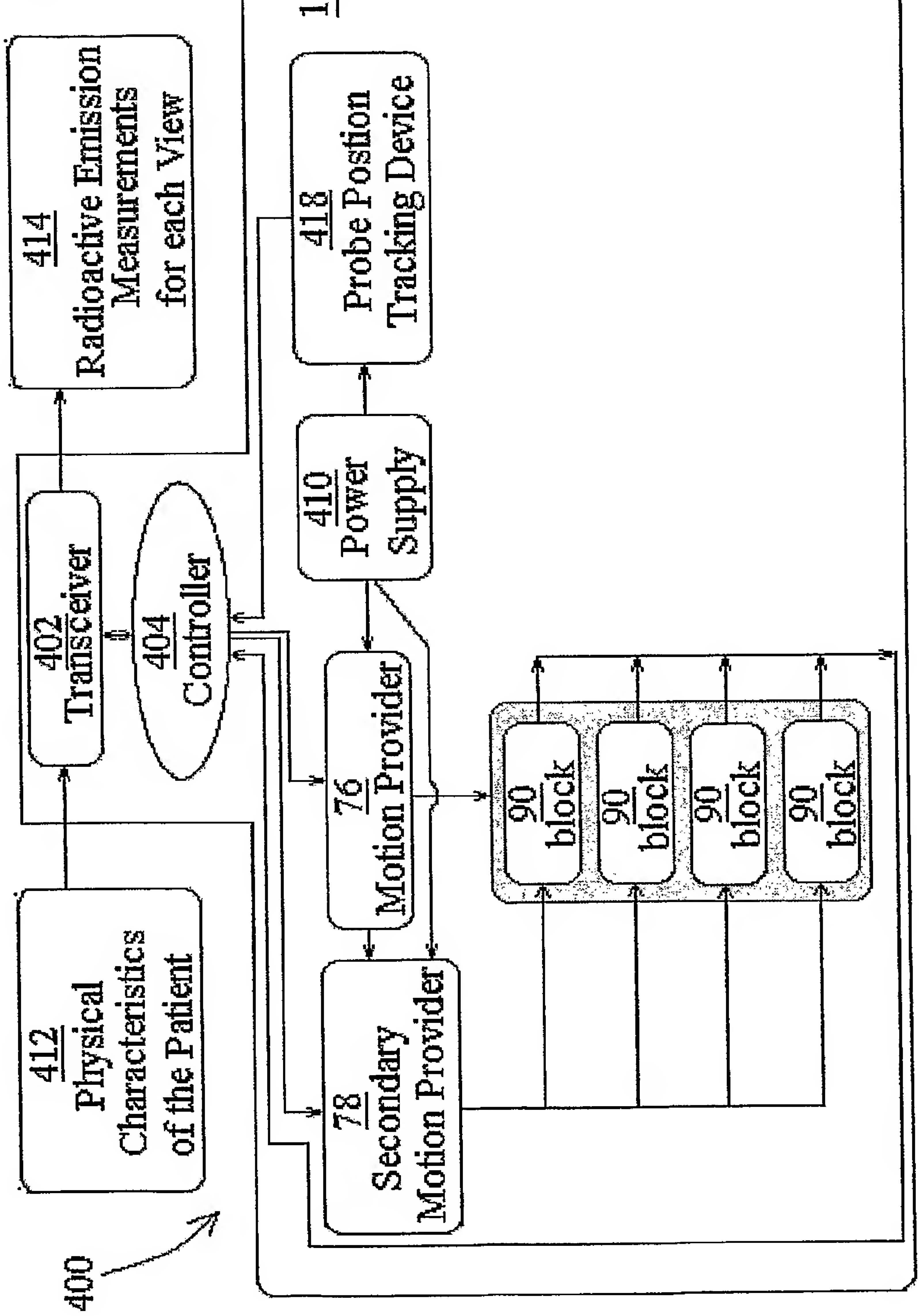

412
Physical
Characteristics
of the Patient
402
Transceiver
414
Radioactive Emission
Measurements
for each View
410
Power
Supply
418
Probe Postion
Tracking Device
404
Controller
76
Motion
Provider
90
block
90
block
90
block
90
block
400
10

Figure 23B

Figure 23C


414
Radioactive Emission Measurements for each View
10
418
Probe Postion Tracking Device
402
Transceiver
404
Controller
410
Power Supply
76
Motion Provider
90
block
90
block
90
block
90
block
412
Physical Characteristics of the Patient
78
Secondary Motion Provider
400

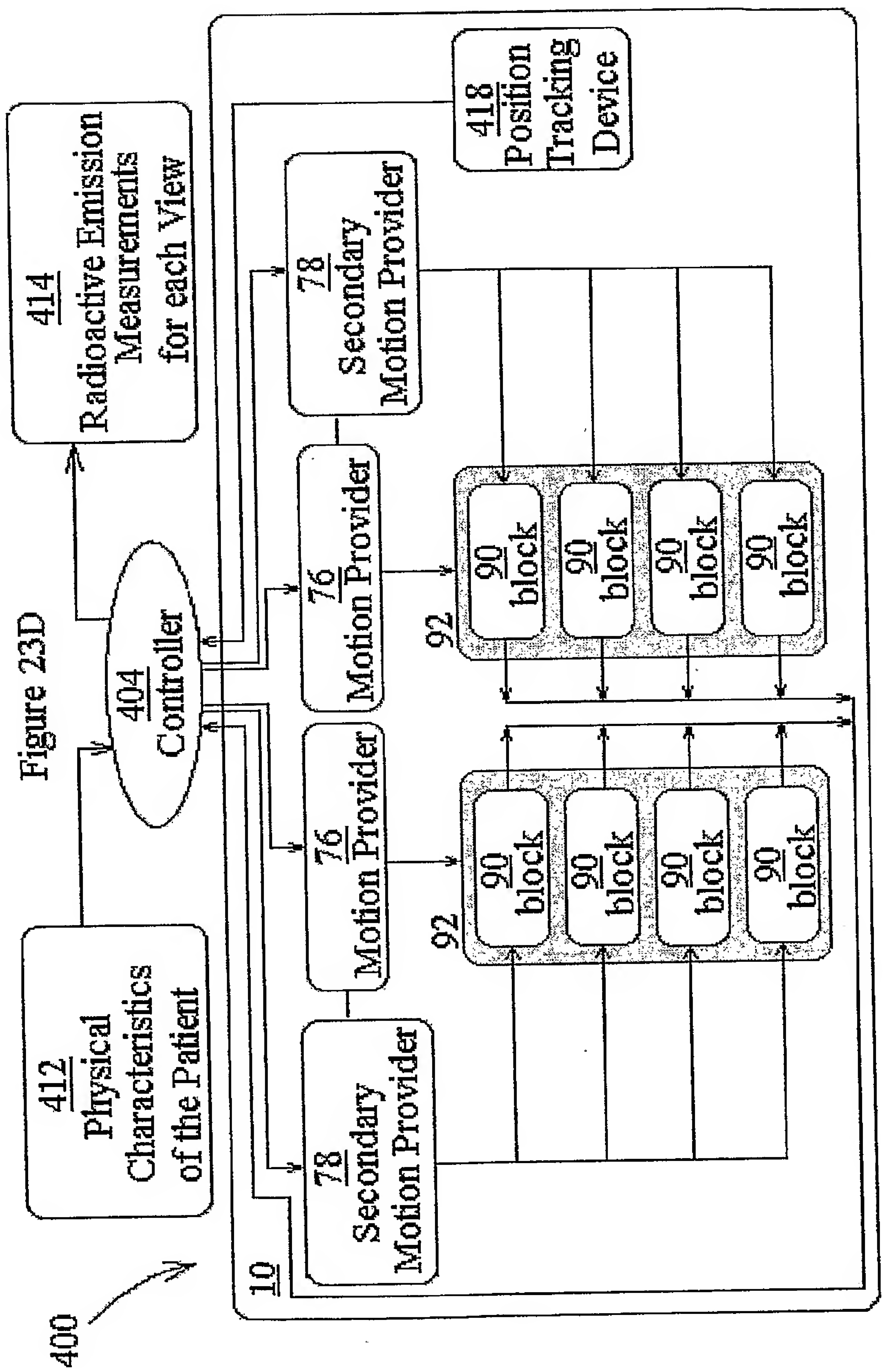

400
412
Physical Characteristics of the Patient
404
Controller
414
Radioactive Emission Measurements for each View
10
78
Secondary Motion Provider
76
Motion Provider
76
Motion Provider
78
Secondary Motion Provider
418
Position Tracking Device
92
90
block
90
block
90
block
90
block
92
90
block
90
block
90
block
90
block

Figure 23D

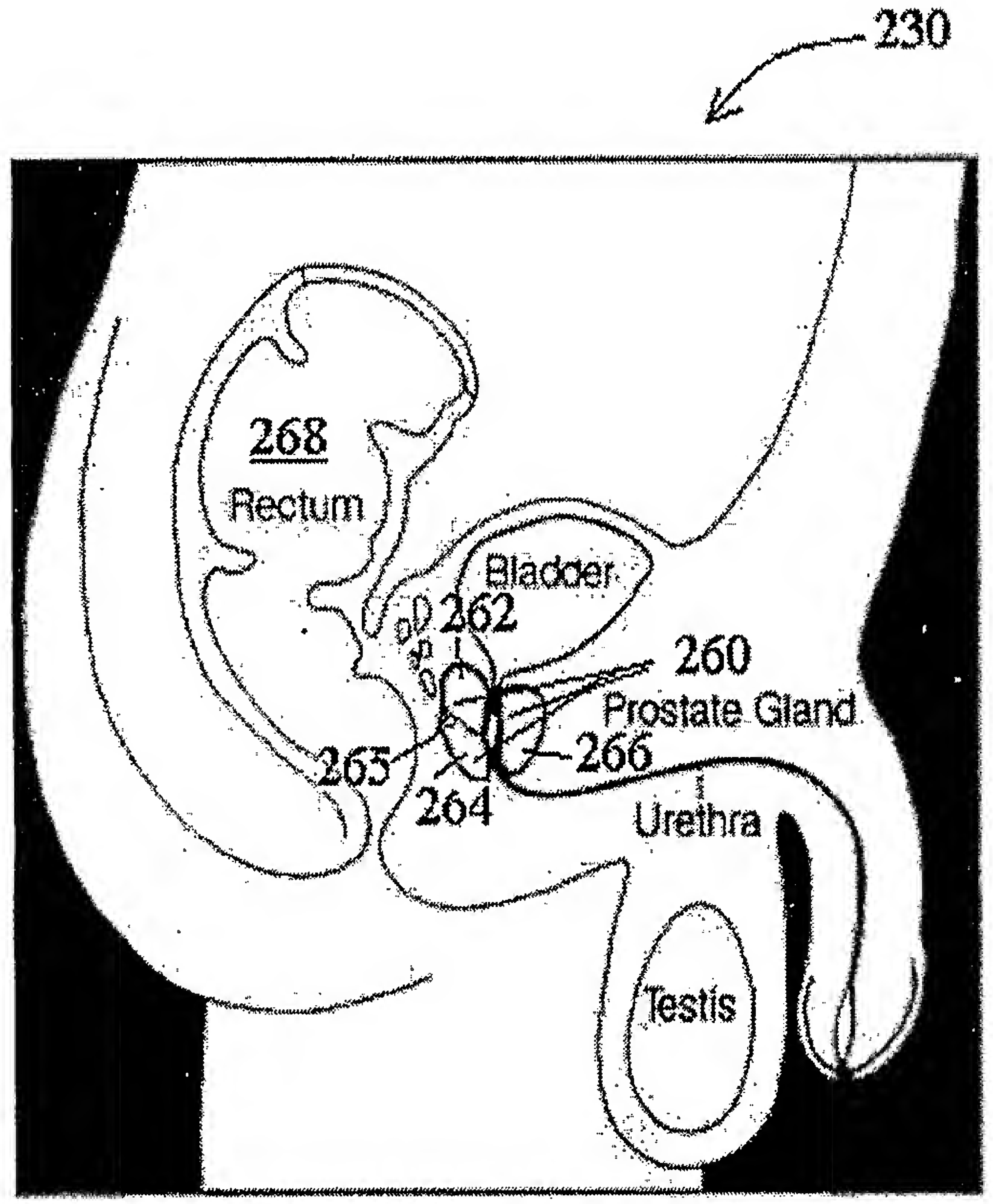


Figure 24A

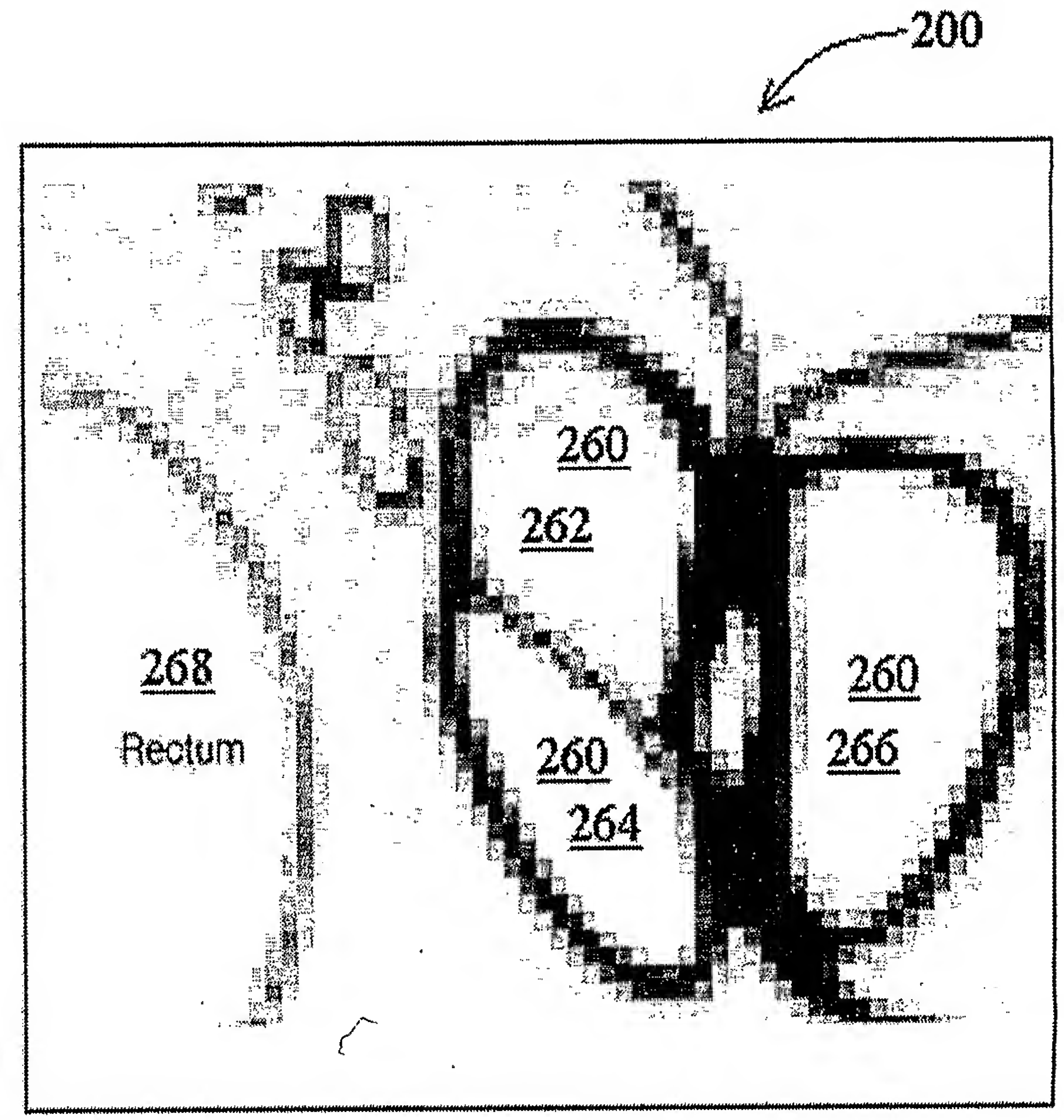


Figure 24B

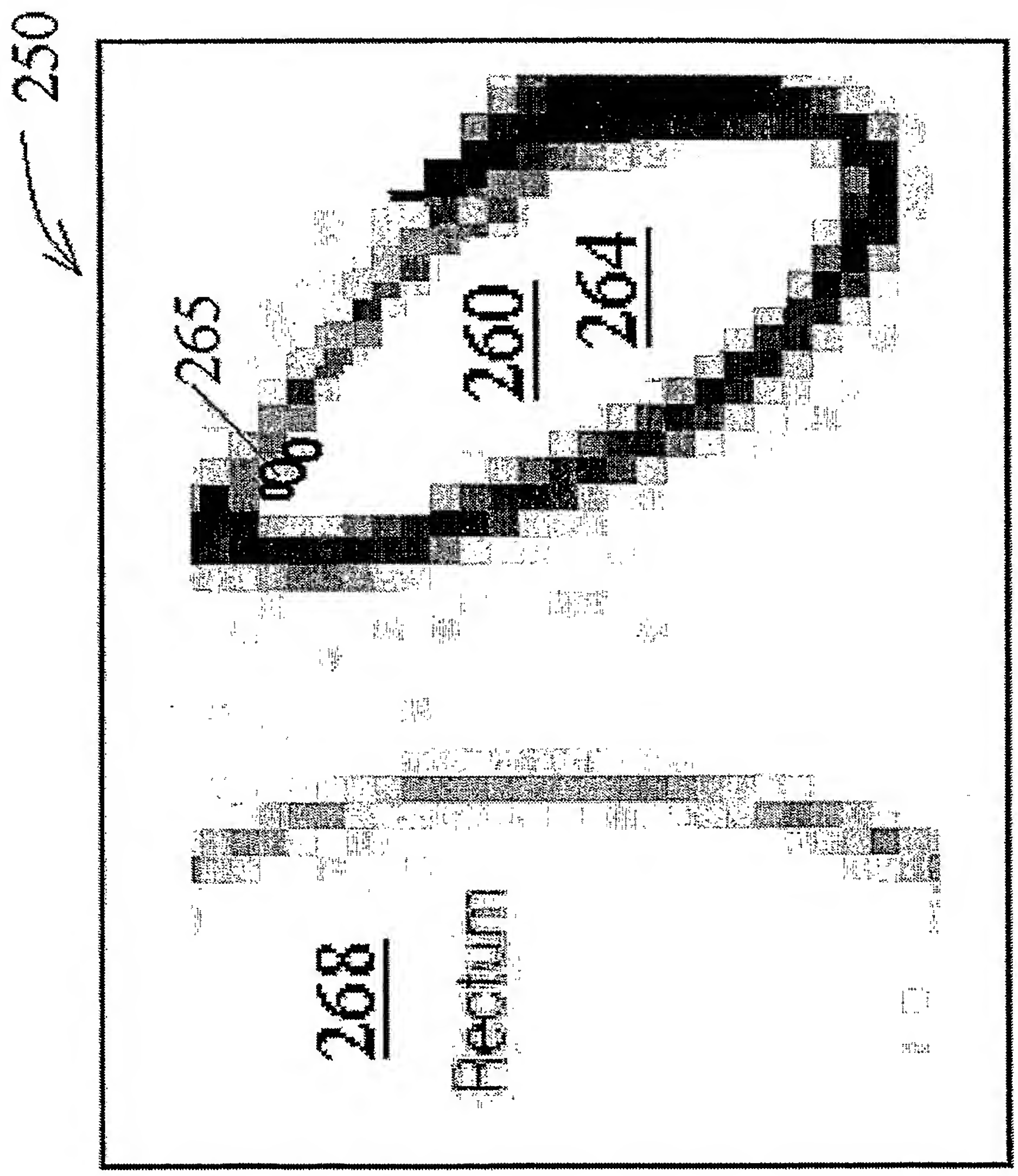


Figure 24C

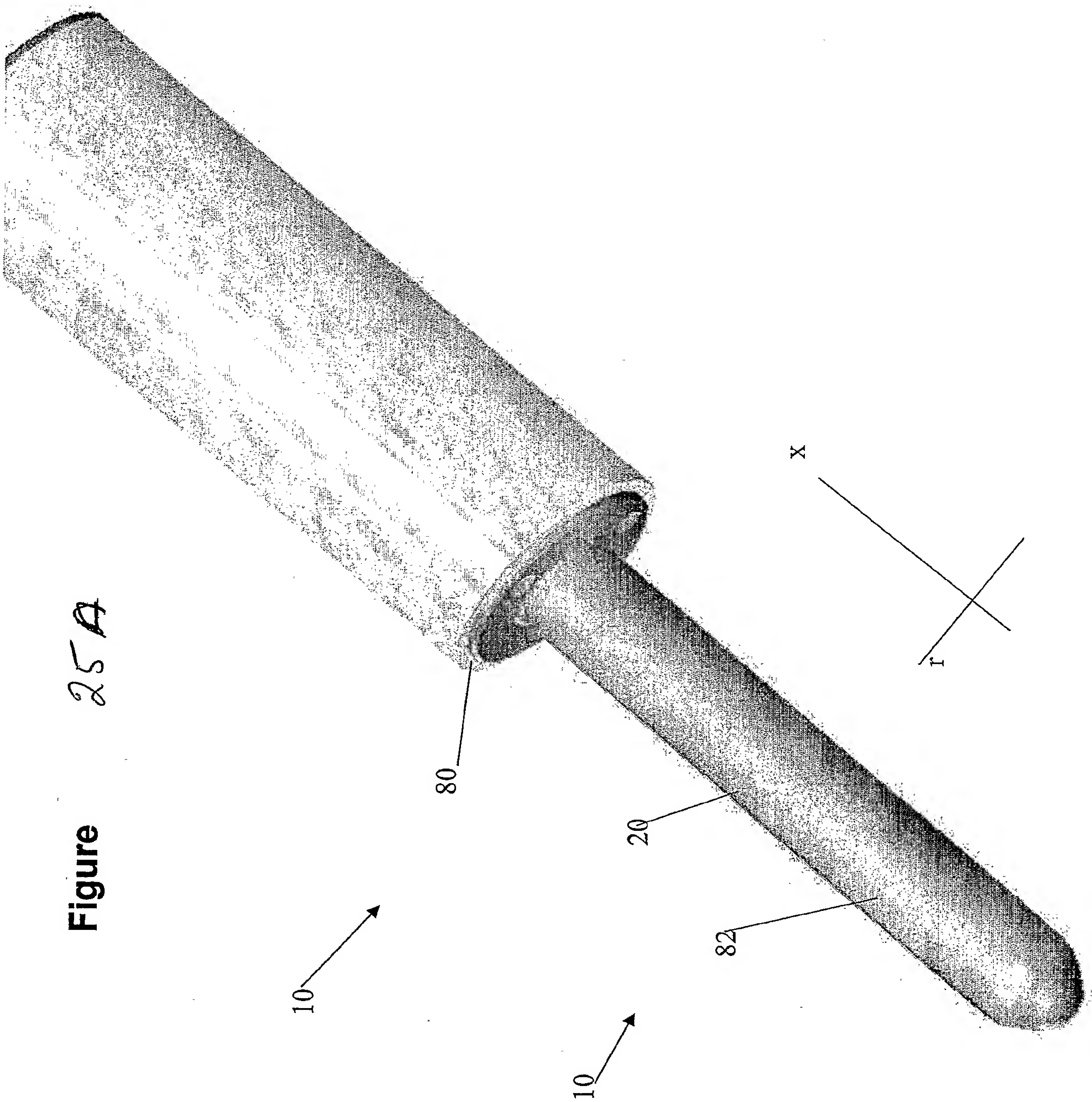


Figure 25A

Prostate Probe-Section

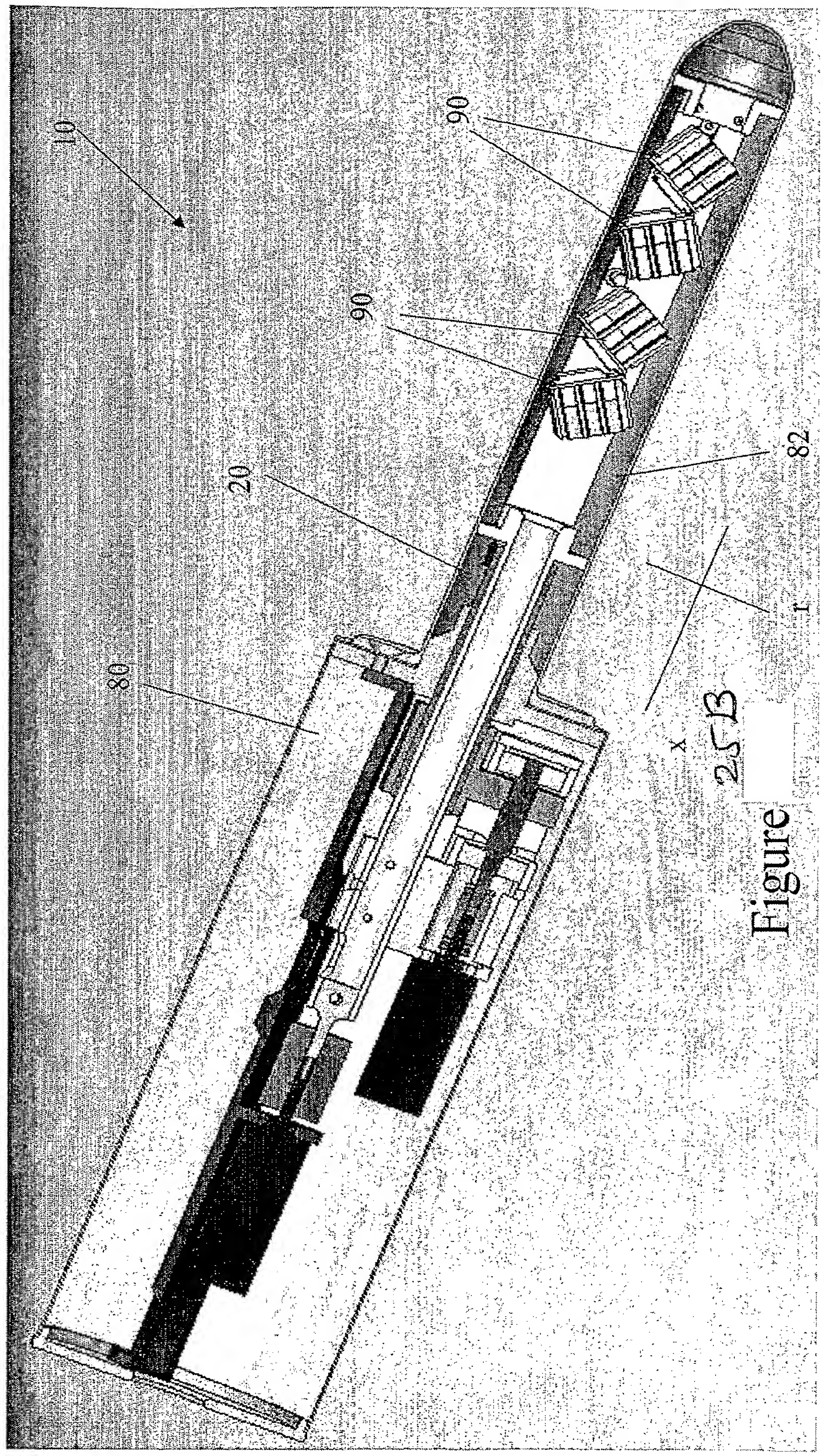


Figure 25B

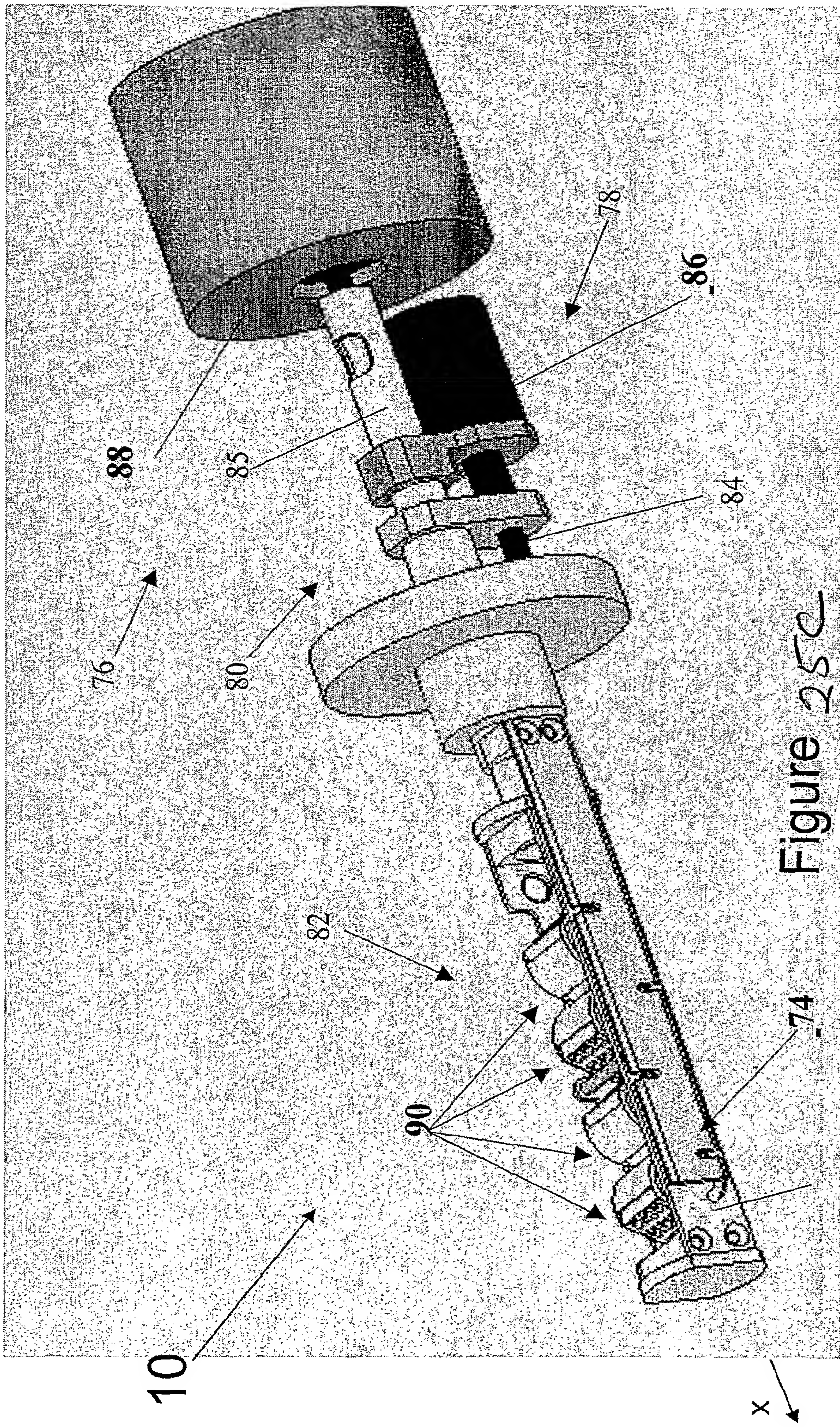


Figure 25C

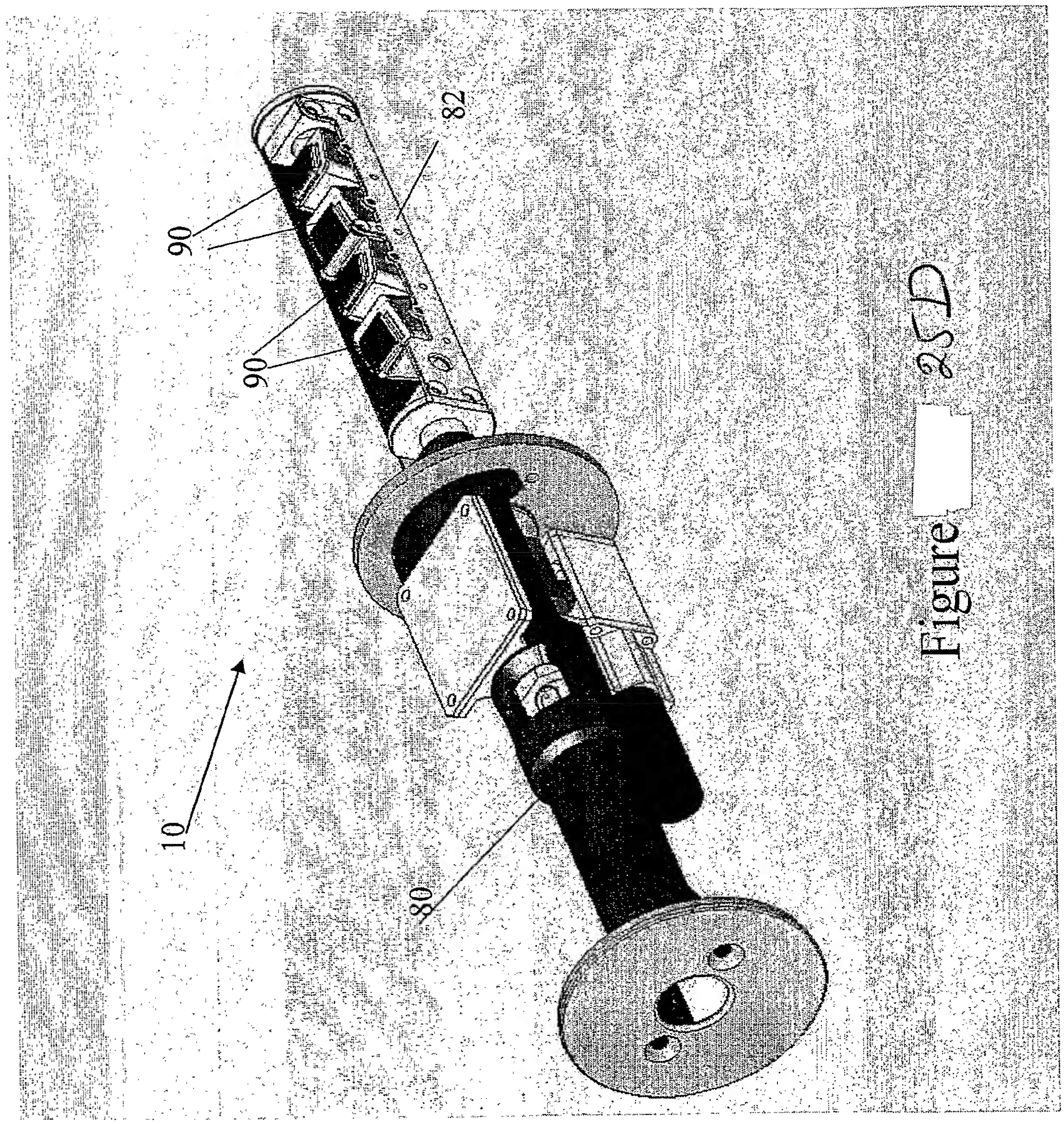


Figure 25D

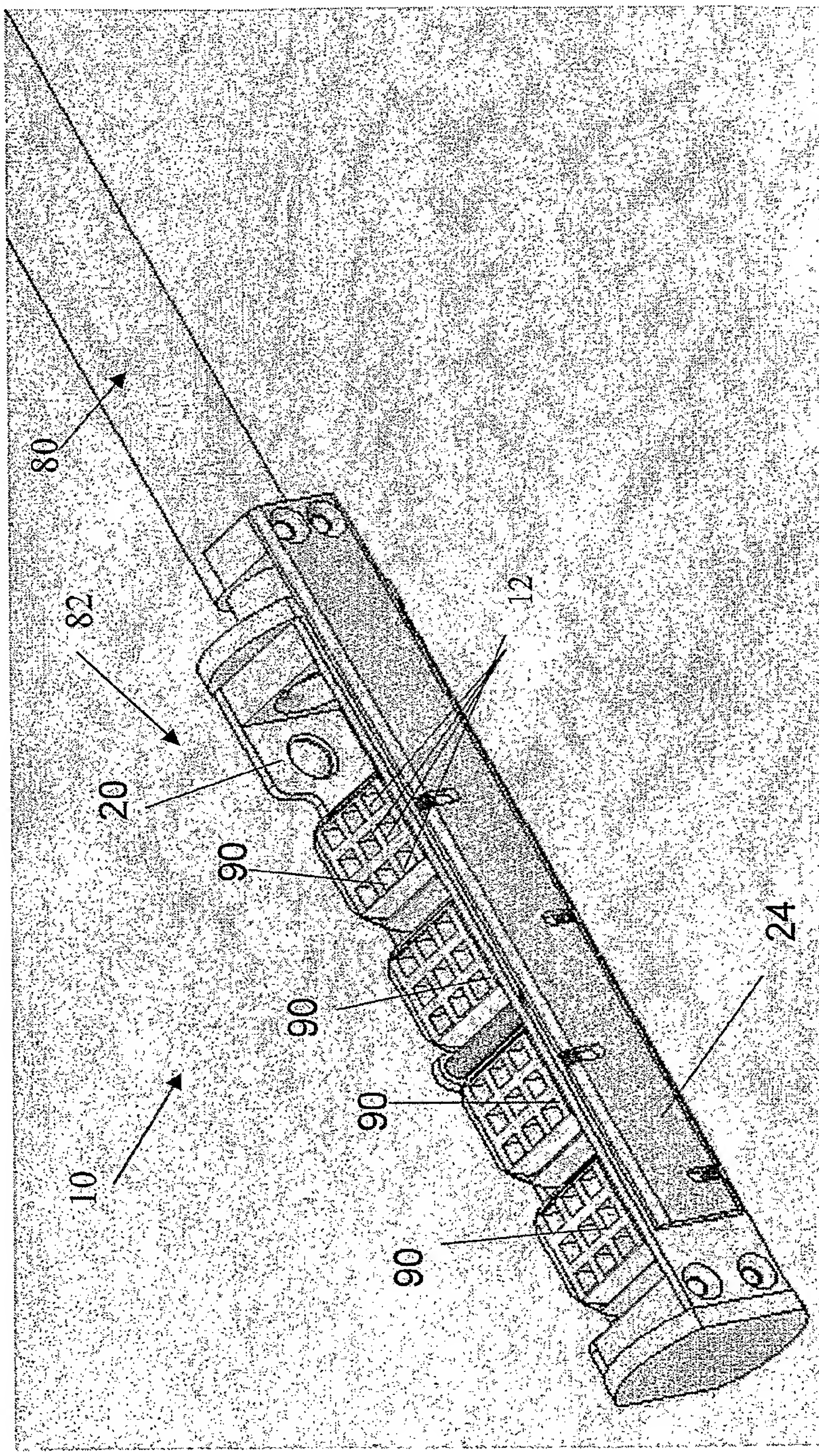


Figure 25 E

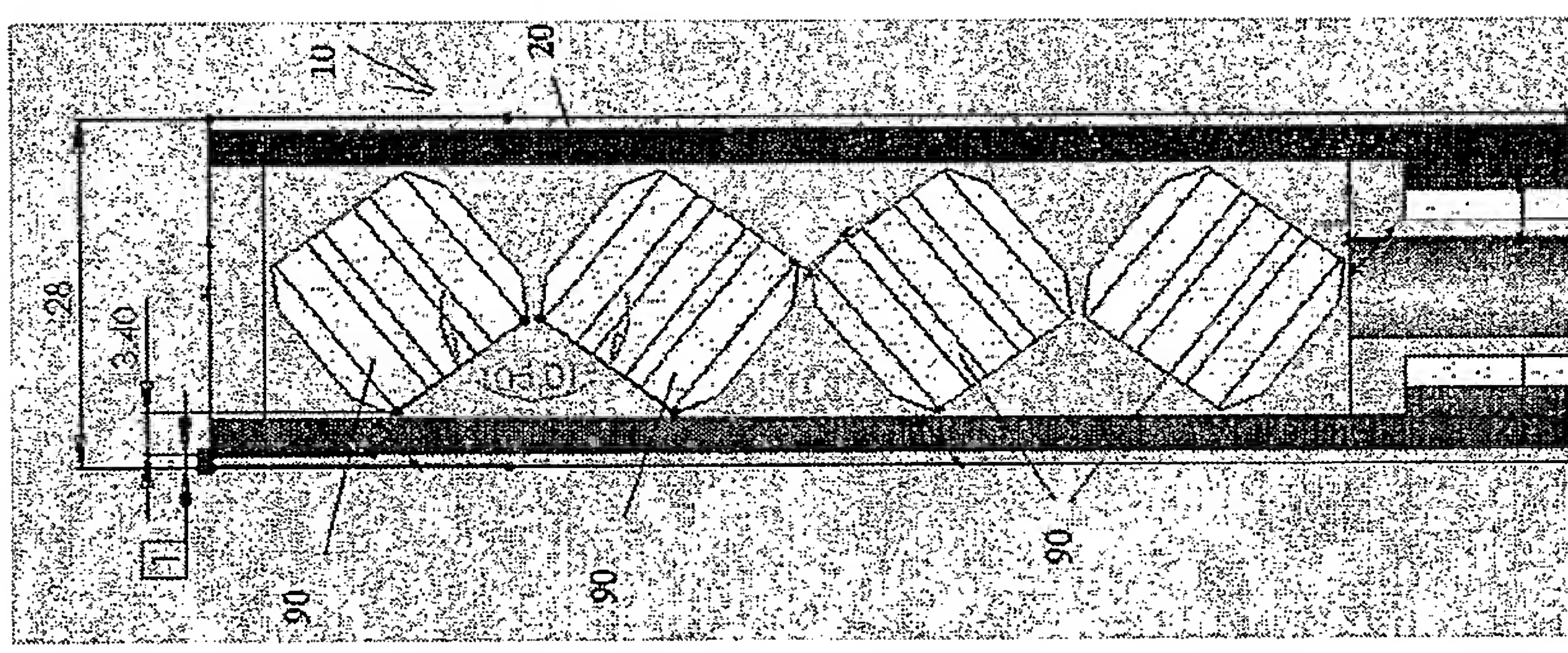


Figure 26

Ultrasound-Nuclear trans-rectal probe

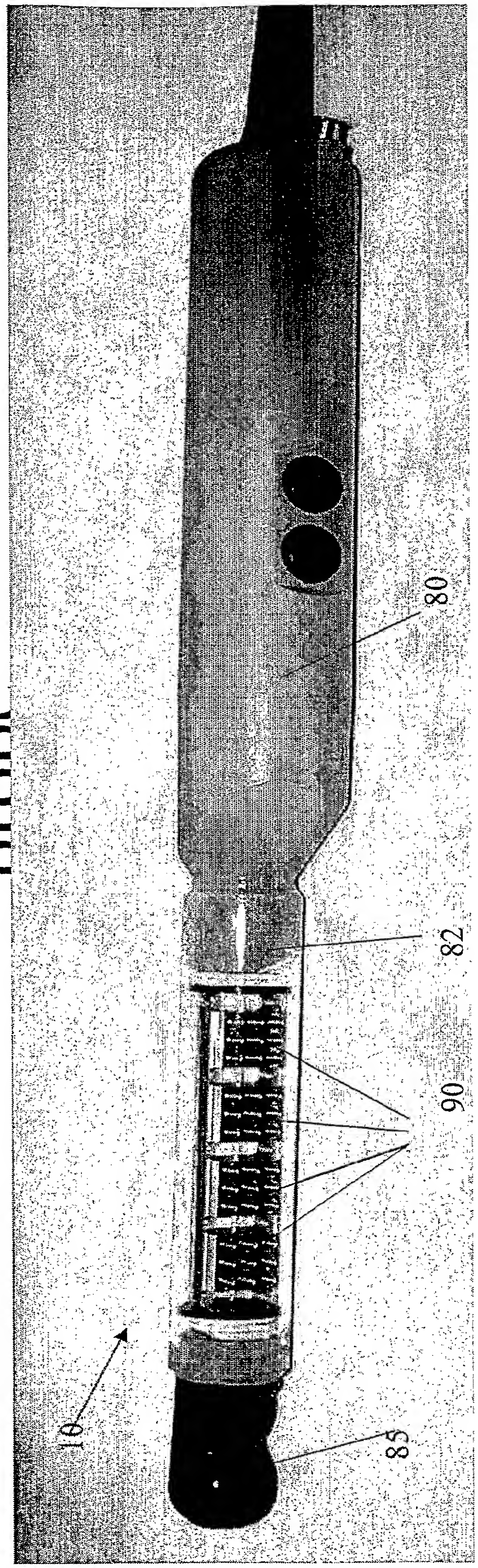


Figure 27

Operation of US-Nuclear transrectal probe

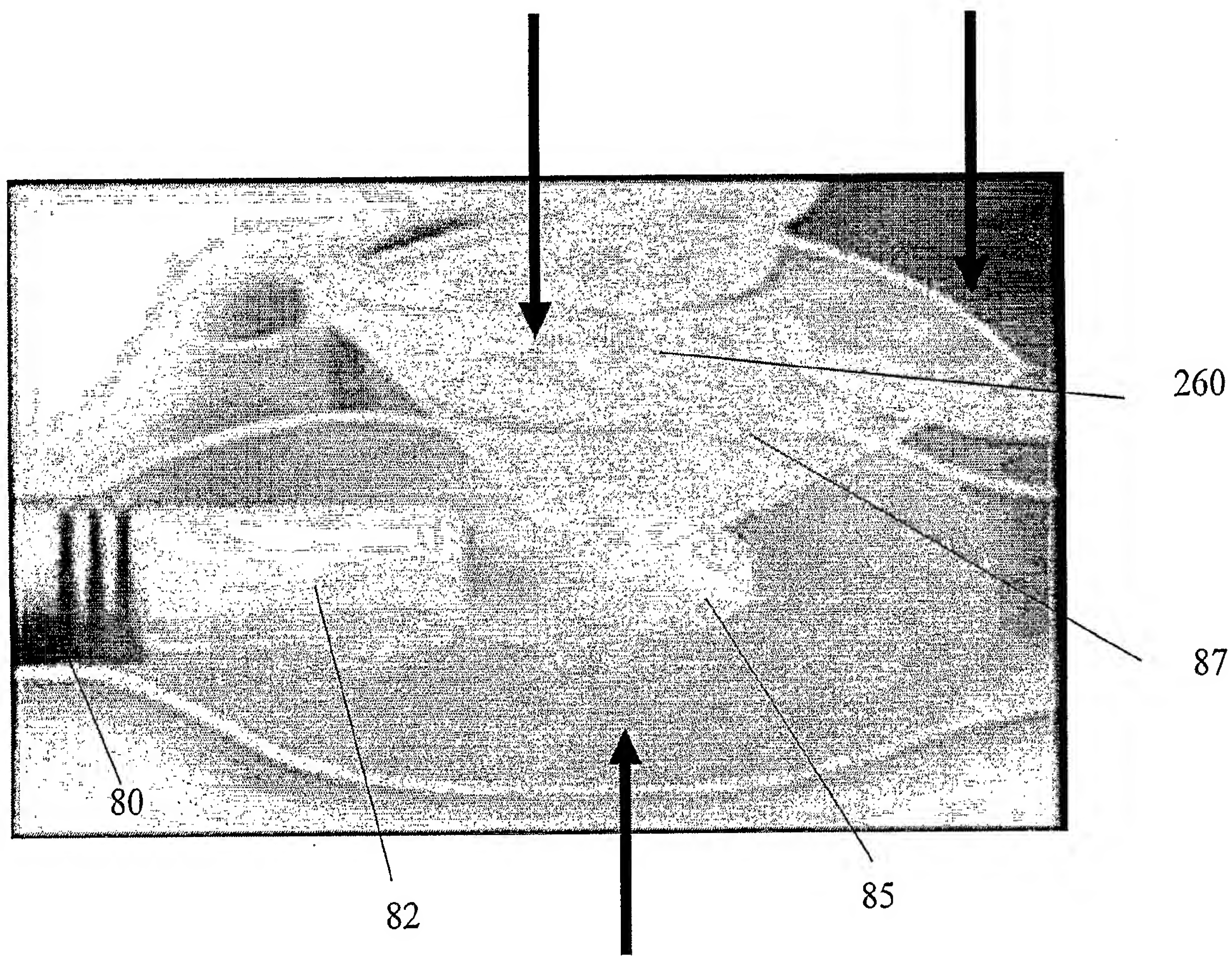


Figure 28

Figure 29B

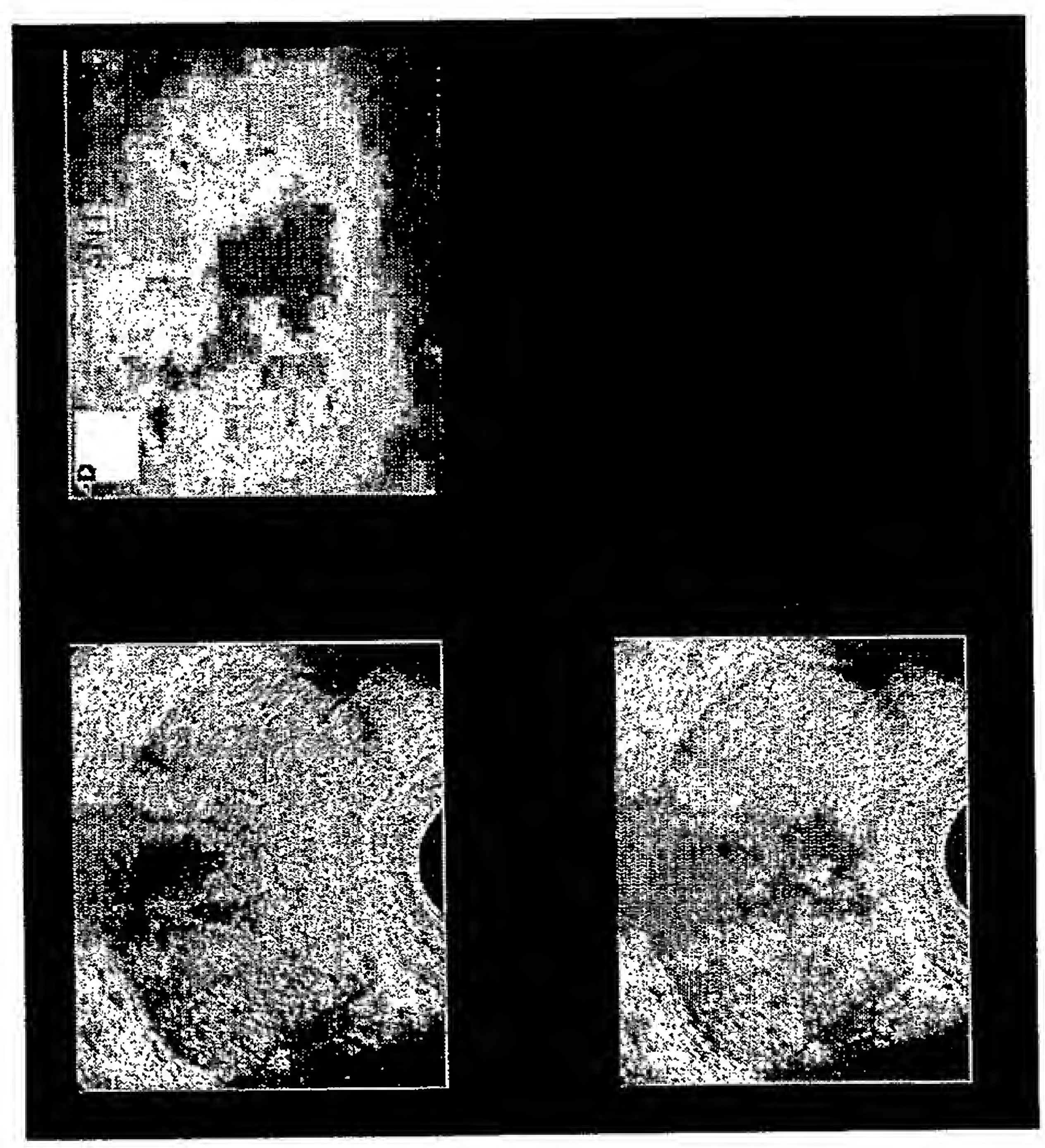


Figure 29A

Figure 29C

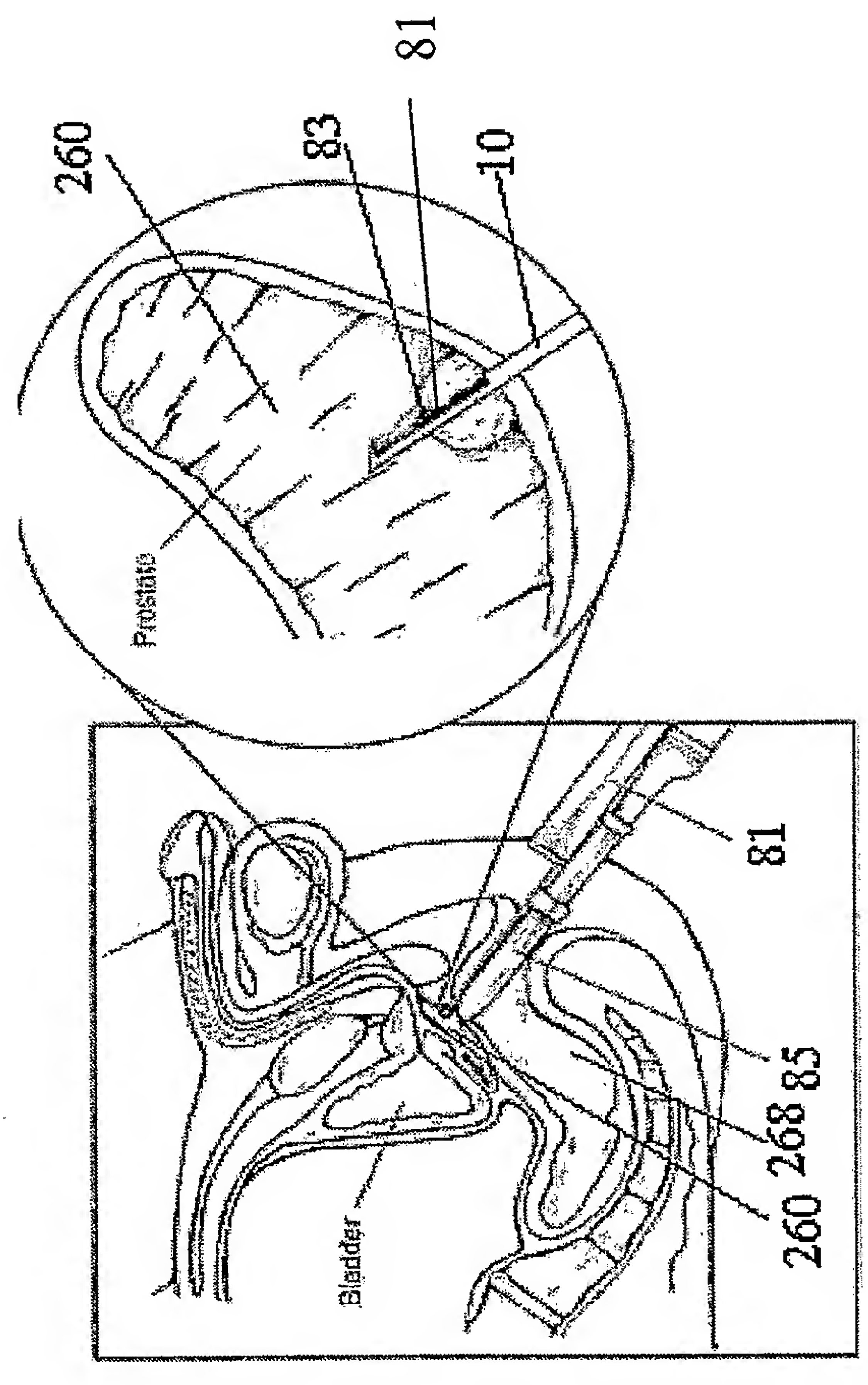


Figure 30

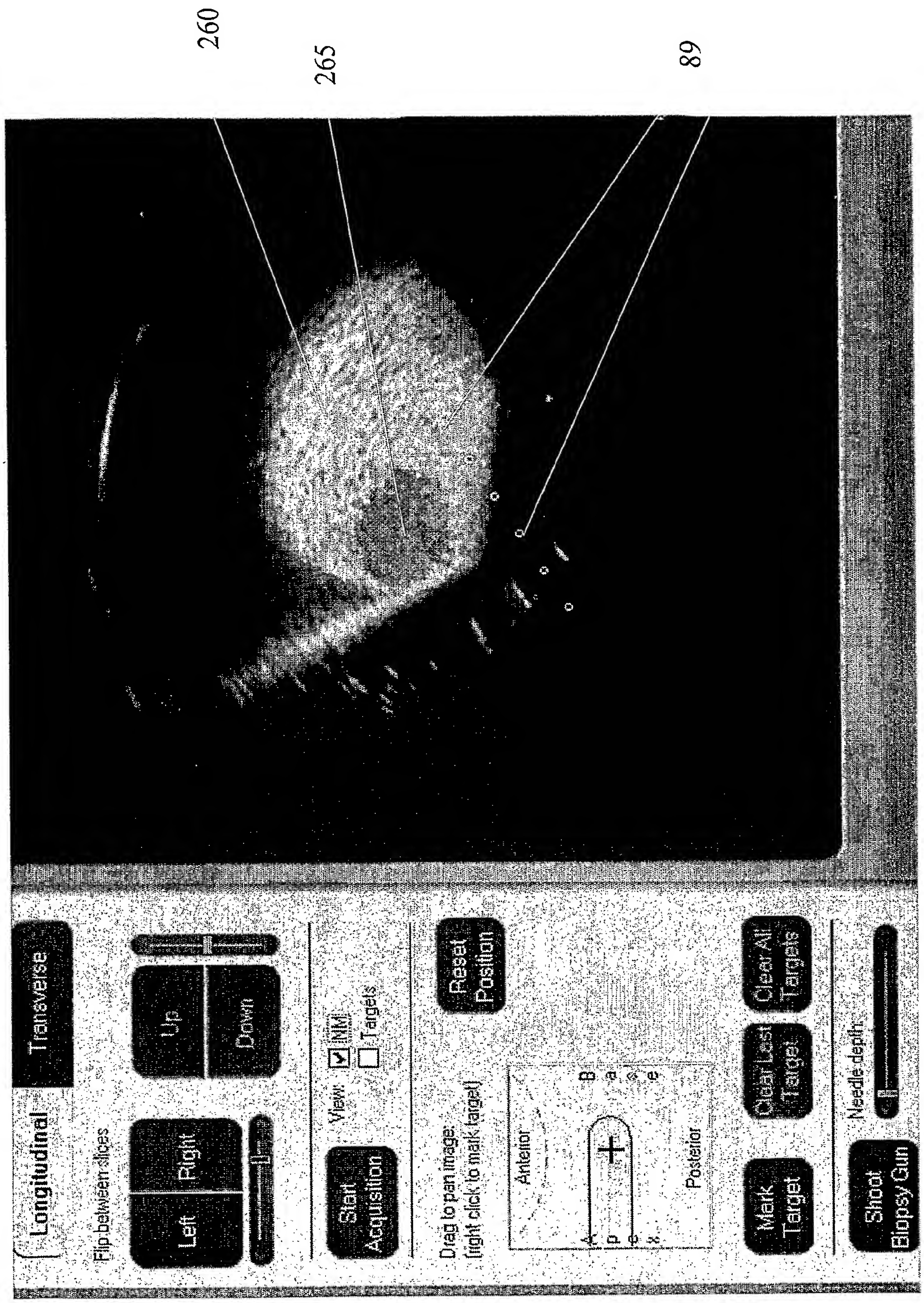

260
265
89
Longitudinal
Transverse
Flip between slices
Left
Right
Up
Down
Start Acquisition
View:
MM
Targets
Drag to pan image:
(right click to mark target)
Reset Position
Anterior
Posterior
Mark Target
Clear Last Target
Clear All Targets
Needle depth:
Shoot Biopsy Gun

Figure 31

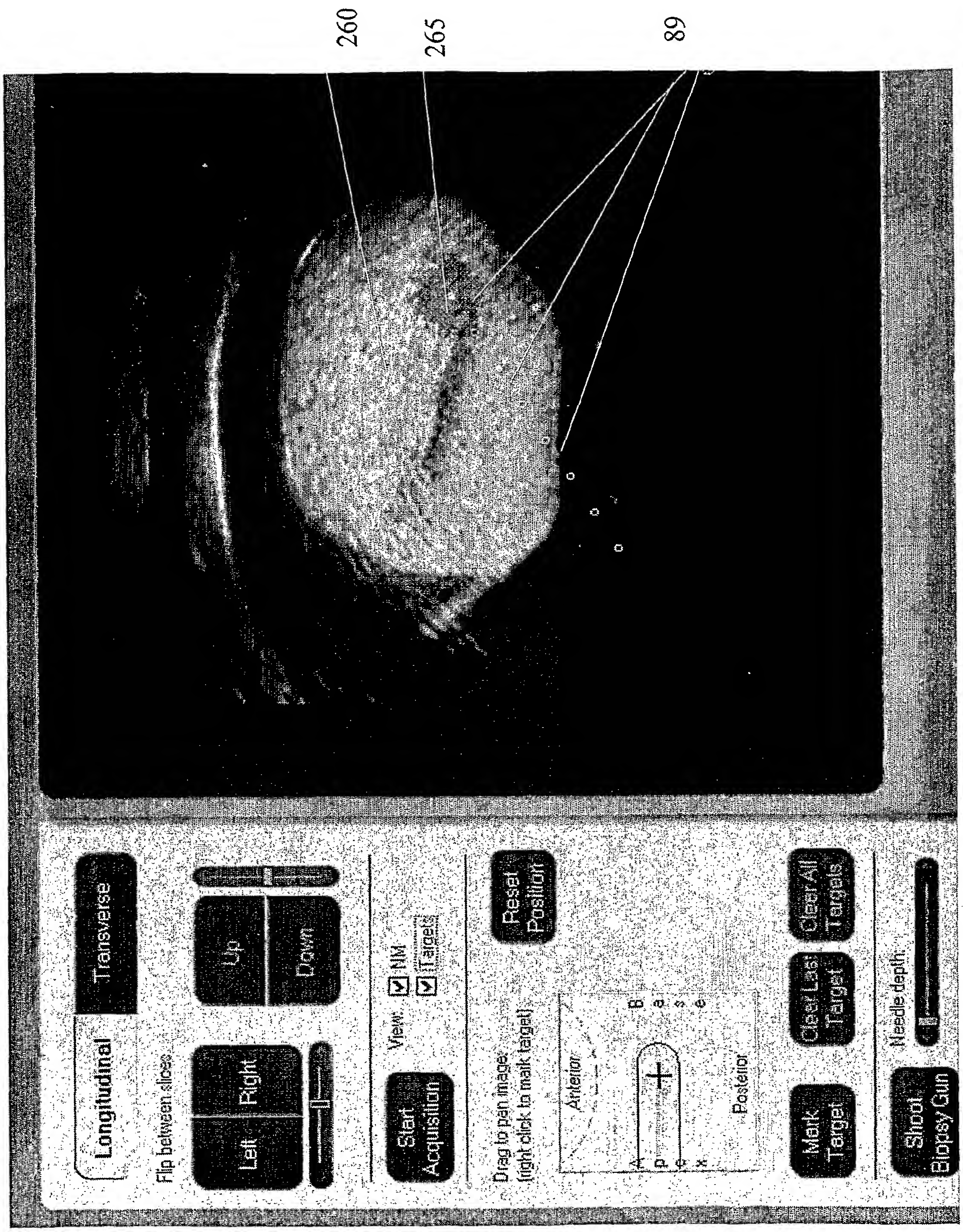

260
265
89
Longitudinal
Transverse
Flip between slices
Left
Right
Up
Down
Start Acquisition
View:
NM
Targets
Reset Position
Drag to pan image
(right click to mark target)
Anterior
Posterior
Mark Target
Clear Last Target
Clear All Targets
Needle depth:
Shoot Biopsy Gun

Figure 32

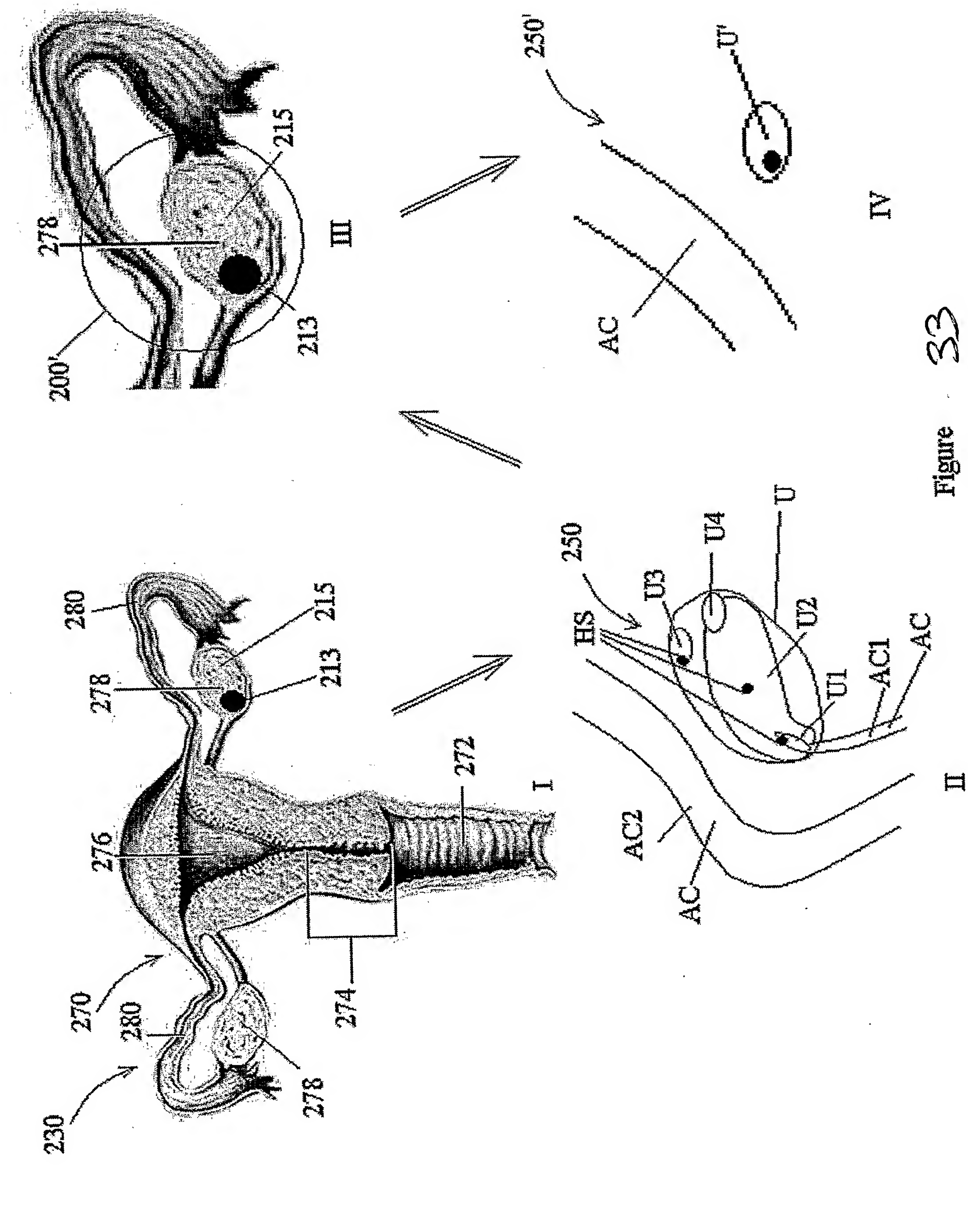

230
270
280
278
274
276
272
215
213
I
AC2
AC
HS
250
U3
U4
U
U2
U1
AC1
II
200'
III
250'
U'
IV

Figure 33

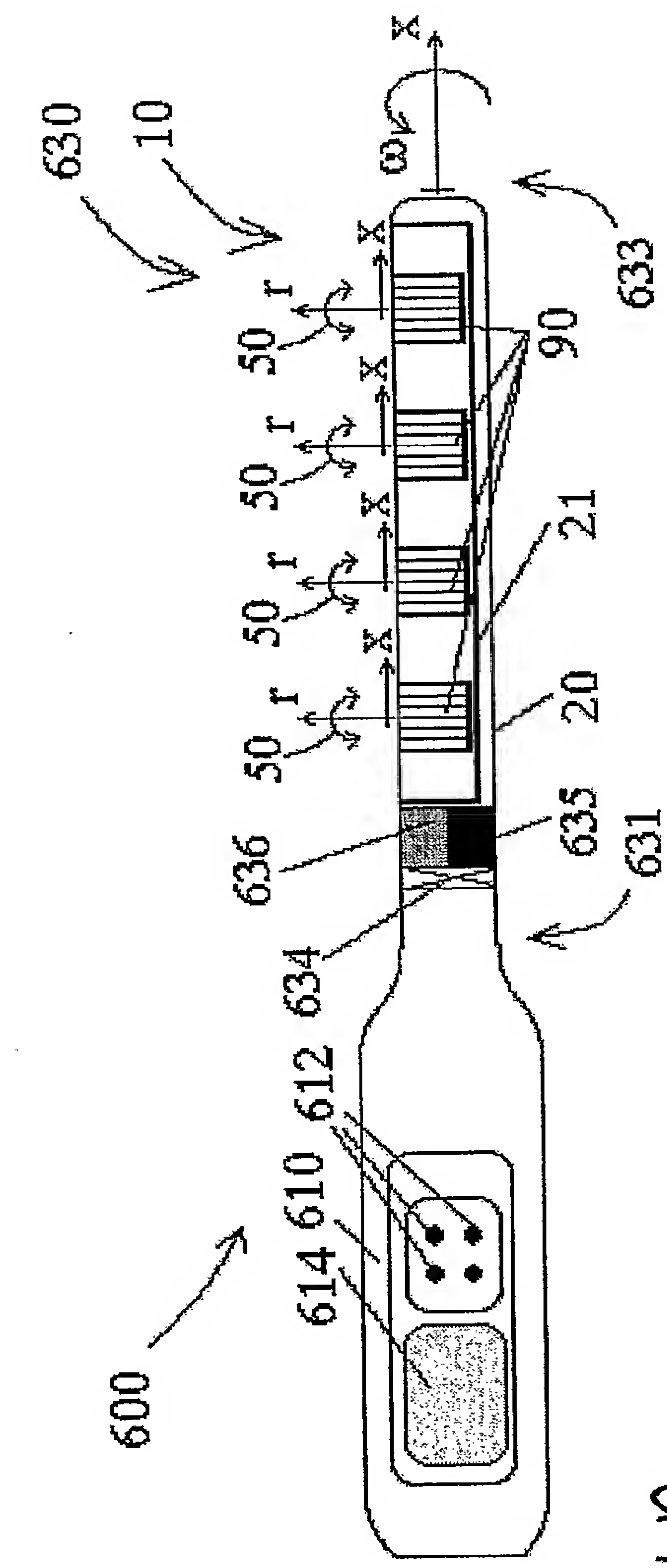
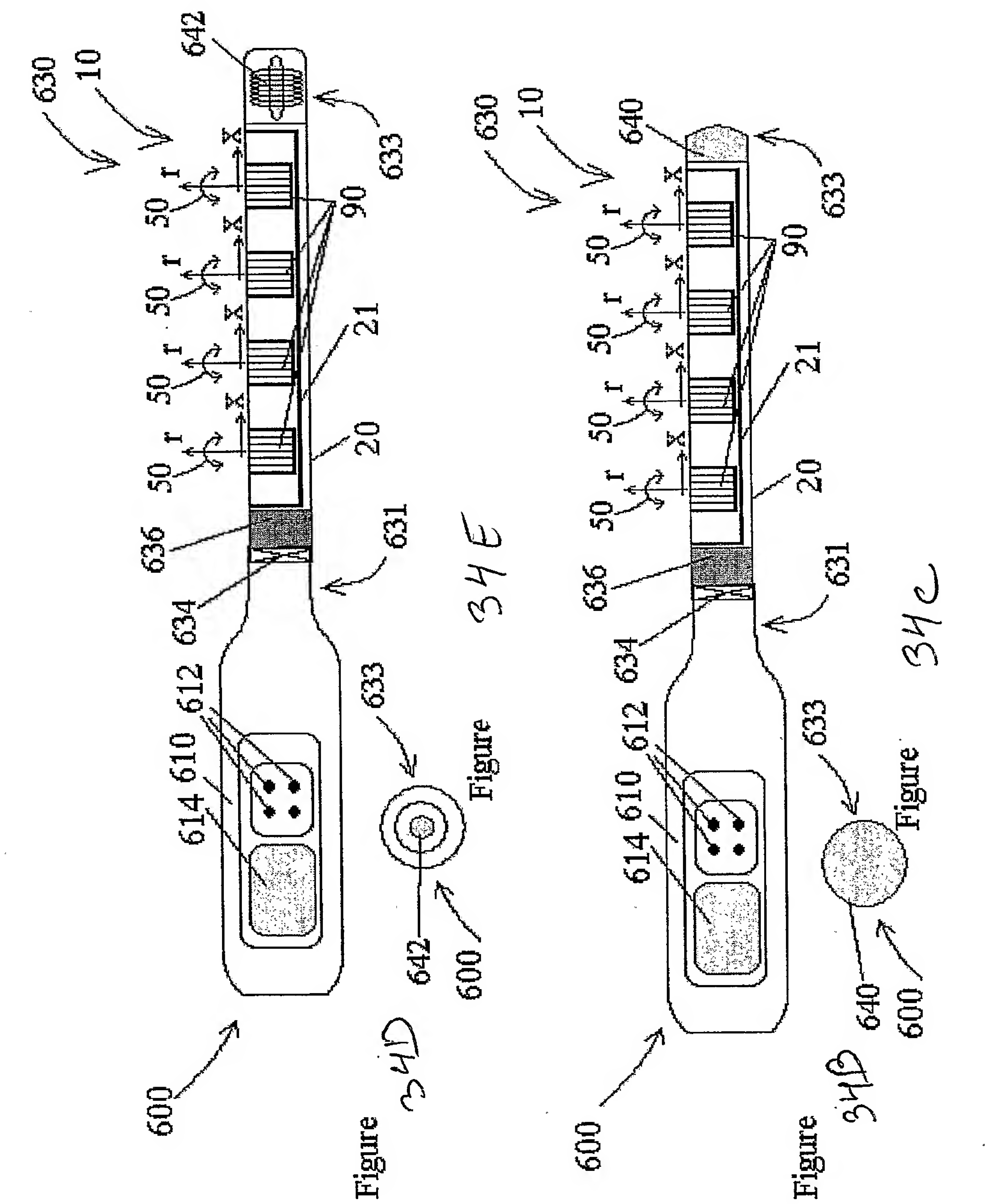


Figure 34a.


630
10
642
633
50
r
X
90
21
20
636
631
634
614 610 612
Figure
34E
34D
600
640
34C
34B

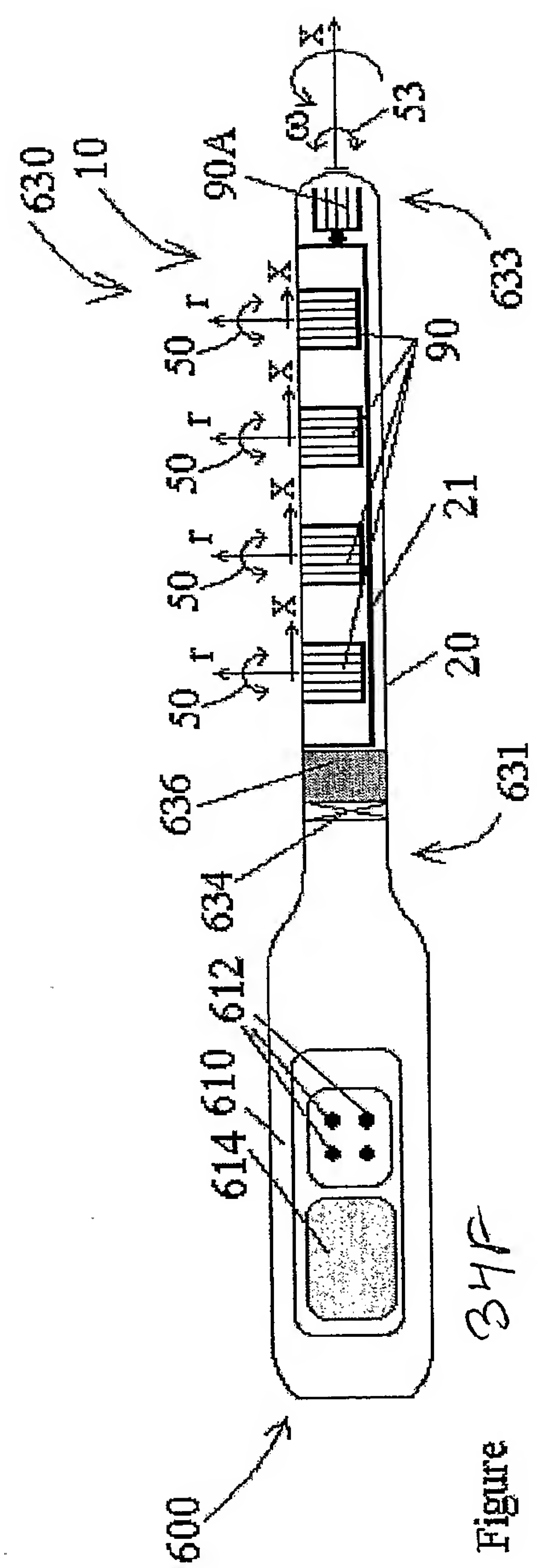


Figure 34F

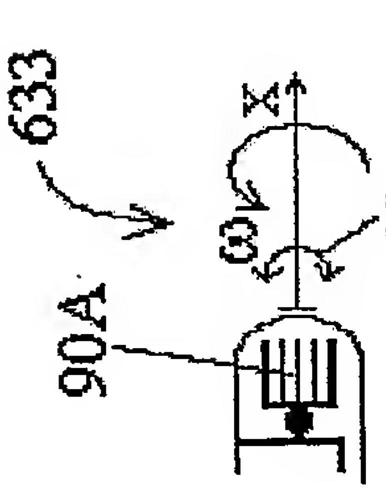


Figure 34G

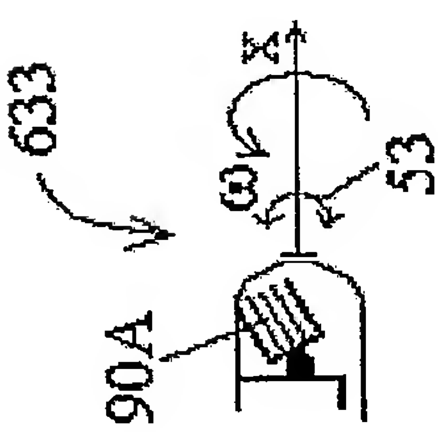


Figure 34H

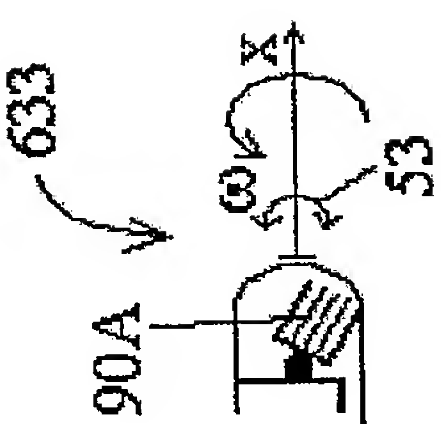


Figure 34I

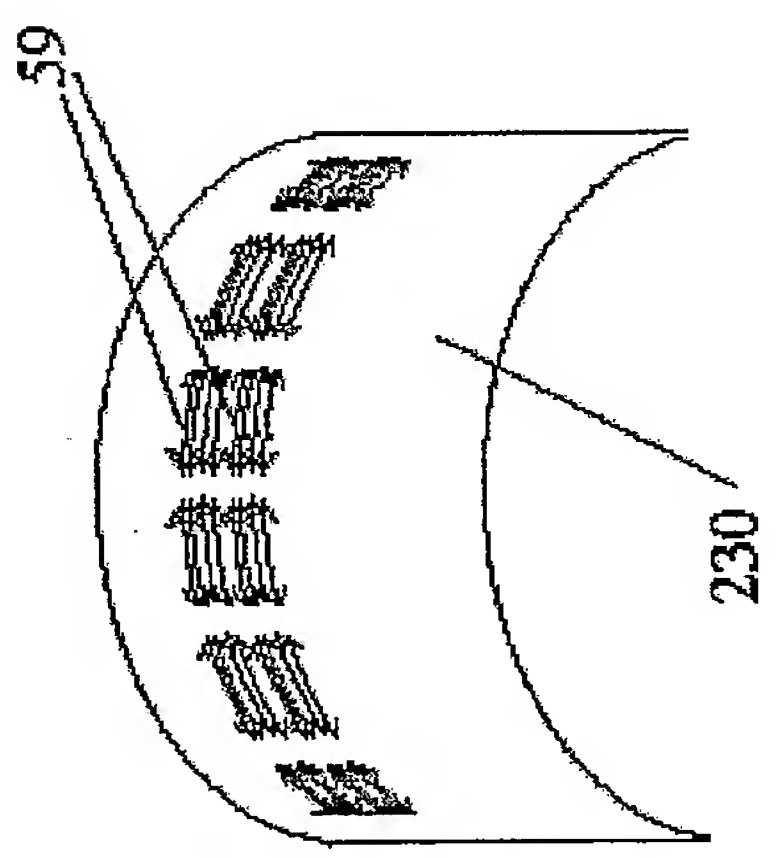


Figure 34J

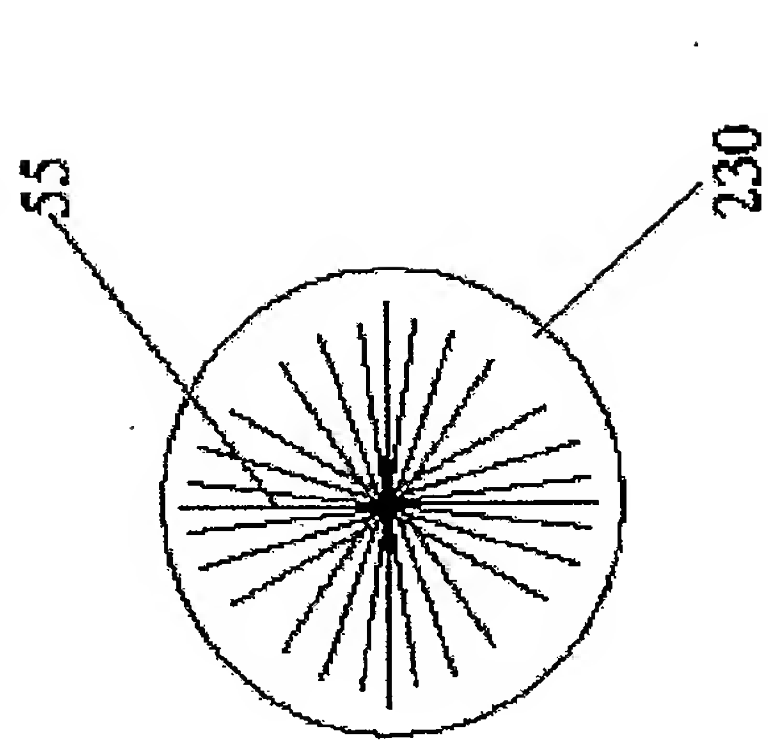


Figure 34K

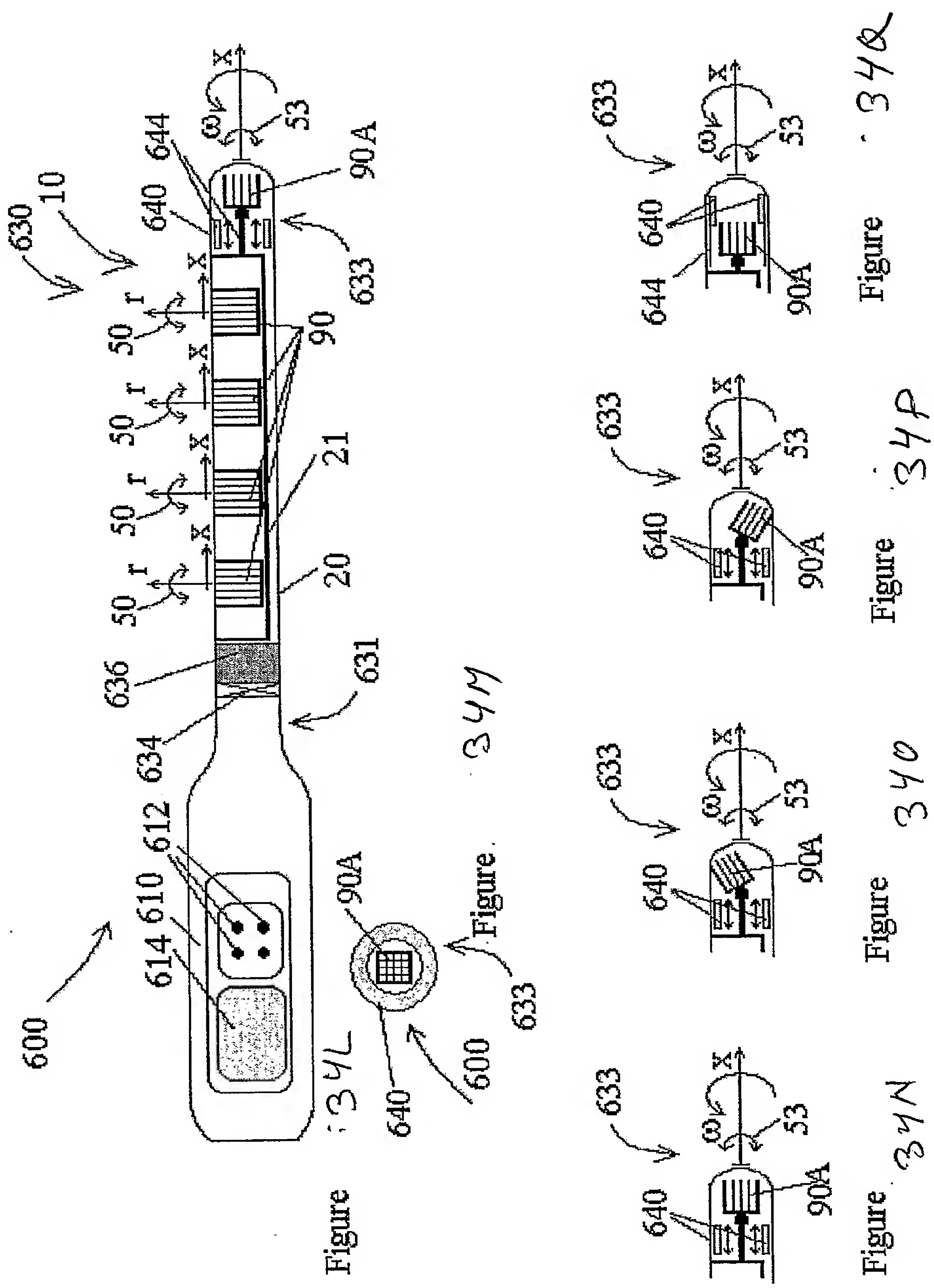


Figure 34L

Figure 34M

Figure 34N

Figure 34O

Figure 34P

Figure 34Q

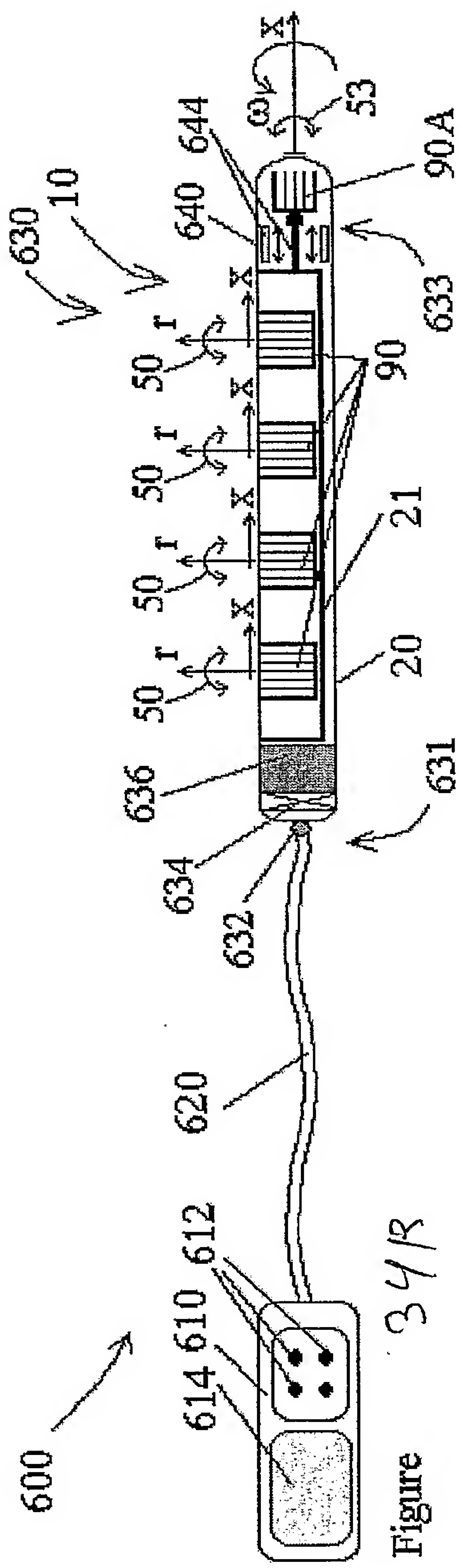

600
614
610
612
620
632
634
631
636
50
r
X
20
21
90
630
10
640
644
633
90A
53
ω

Figure 34R

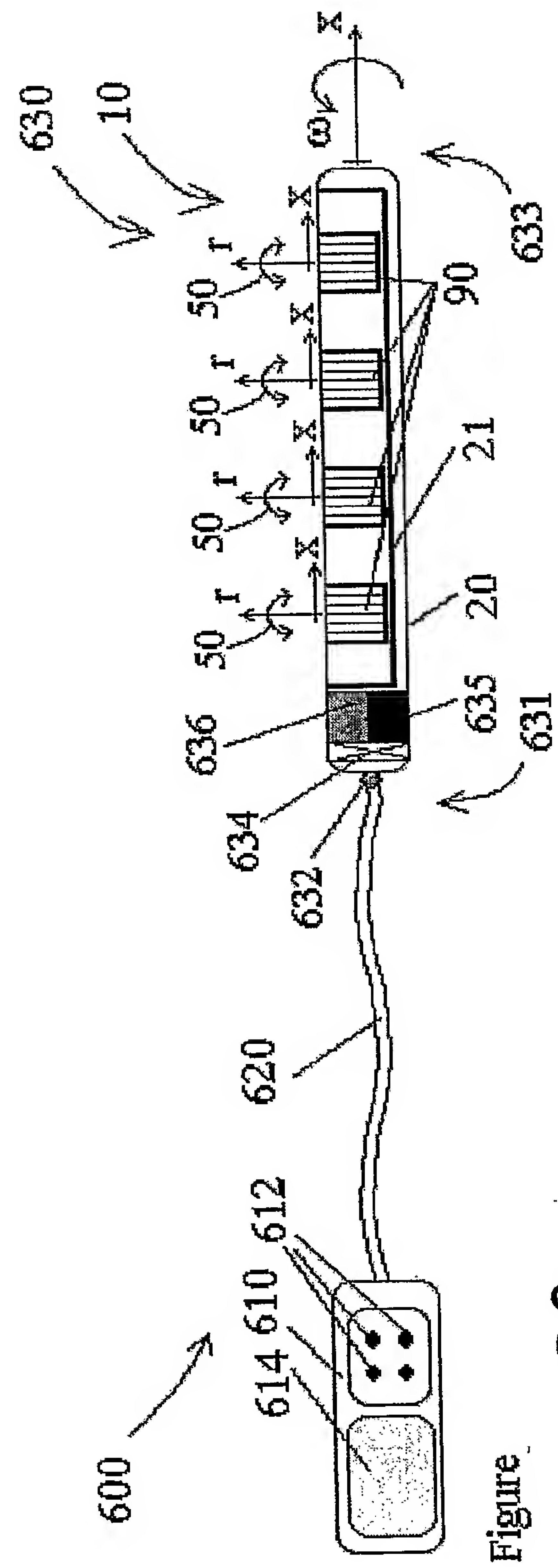

630
10
X
ω
633
50
r
X
90
21
20
636
635
631
634
632
620
612
610
614
600

Figure 35A

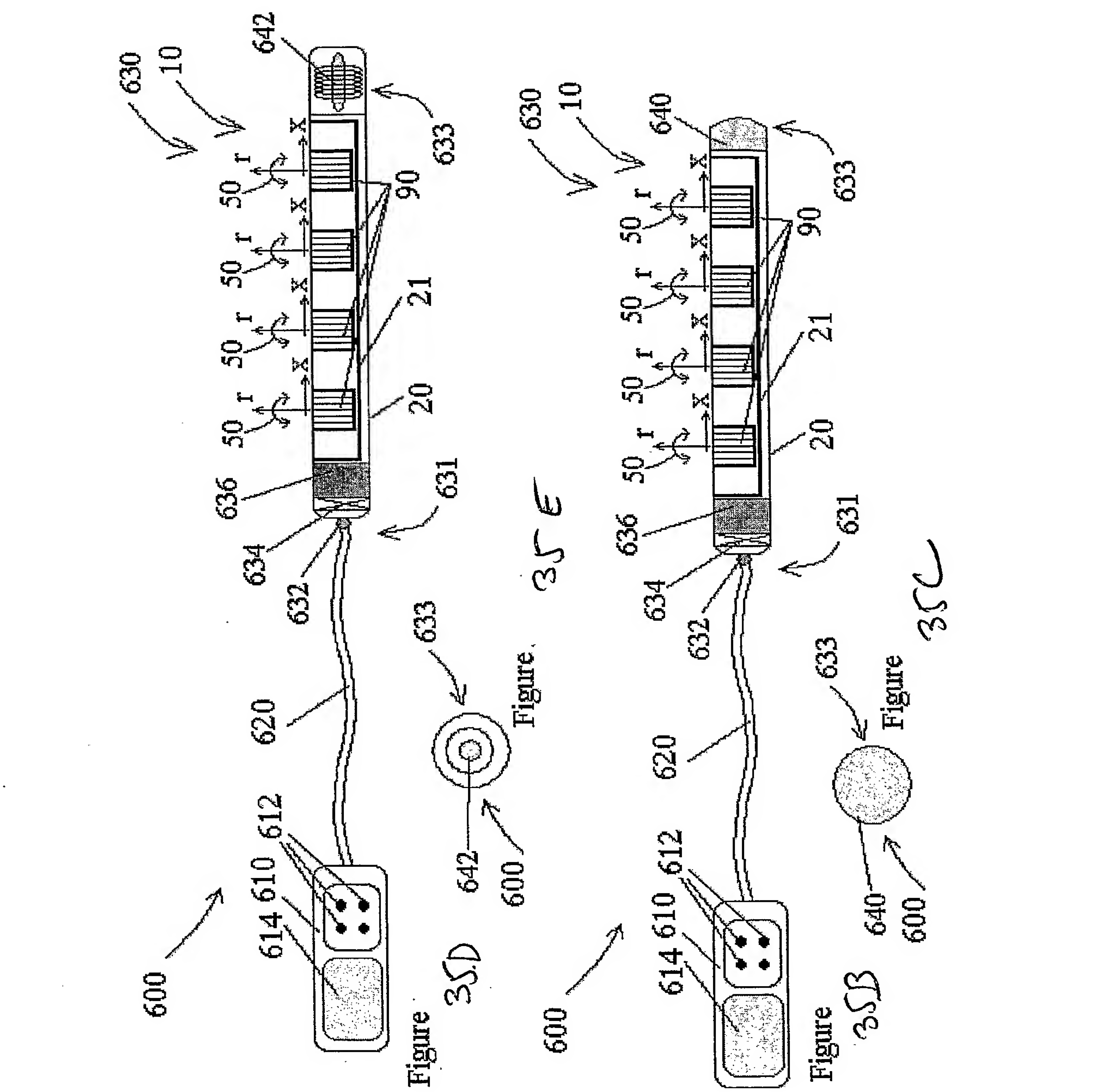


Figure 35B
Figure 35C
Figure 35D
Figure 35E

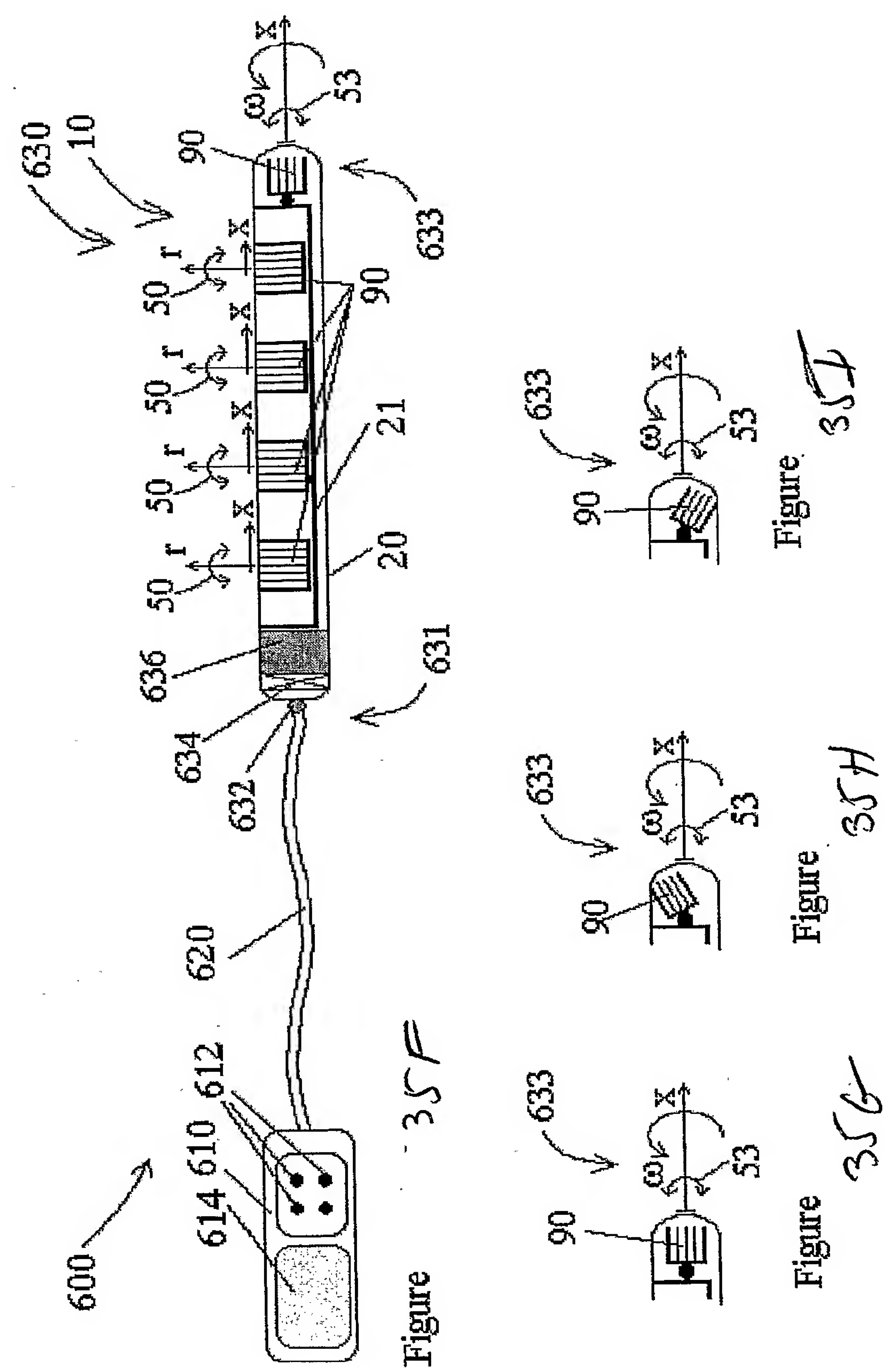


Figure 35F

Figure 35G

Figure 35H

Figure 35I

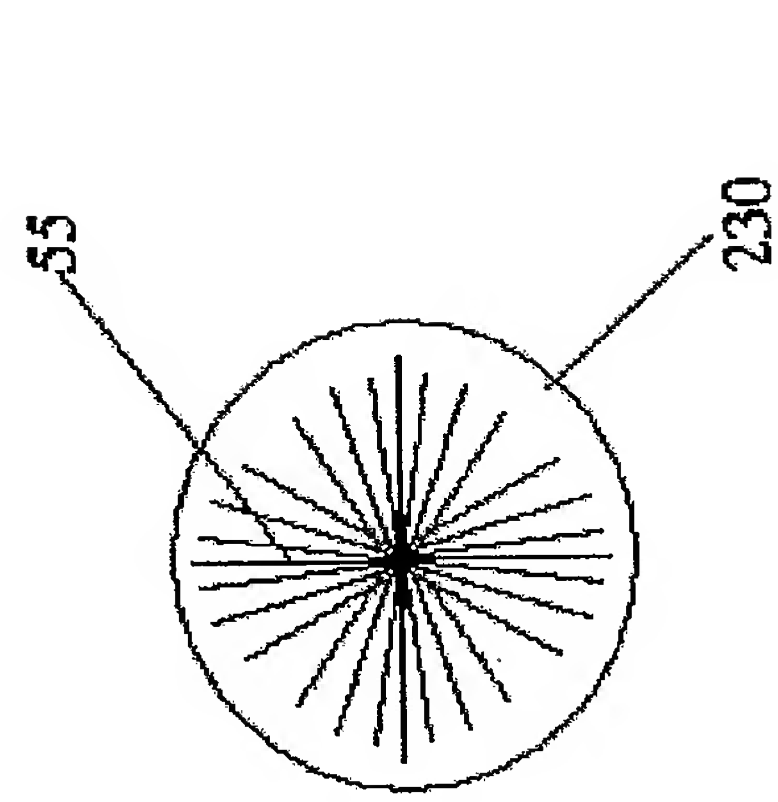


Figure 35K

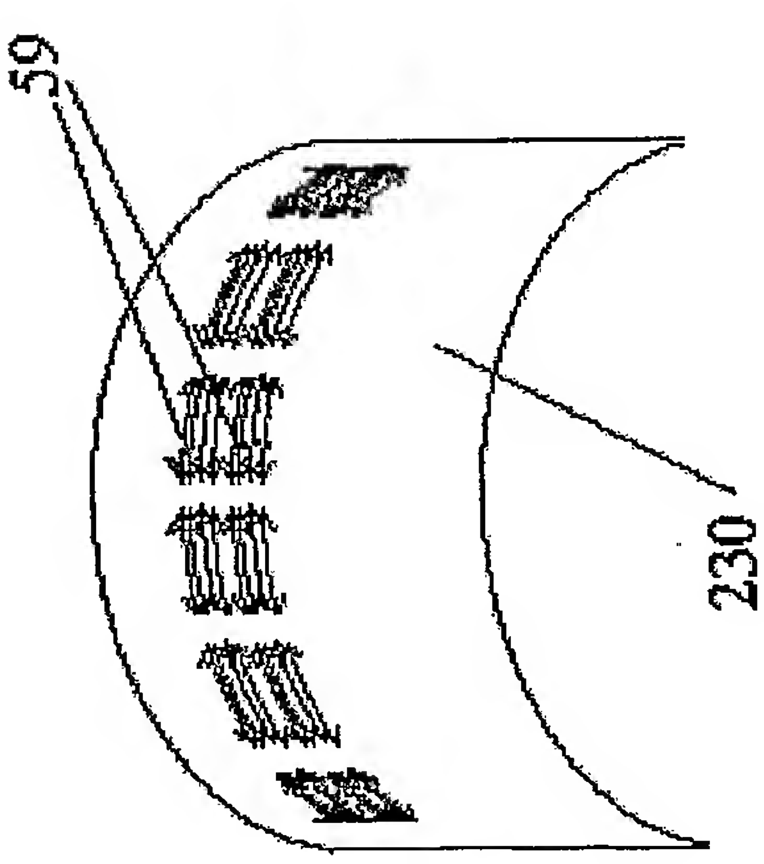
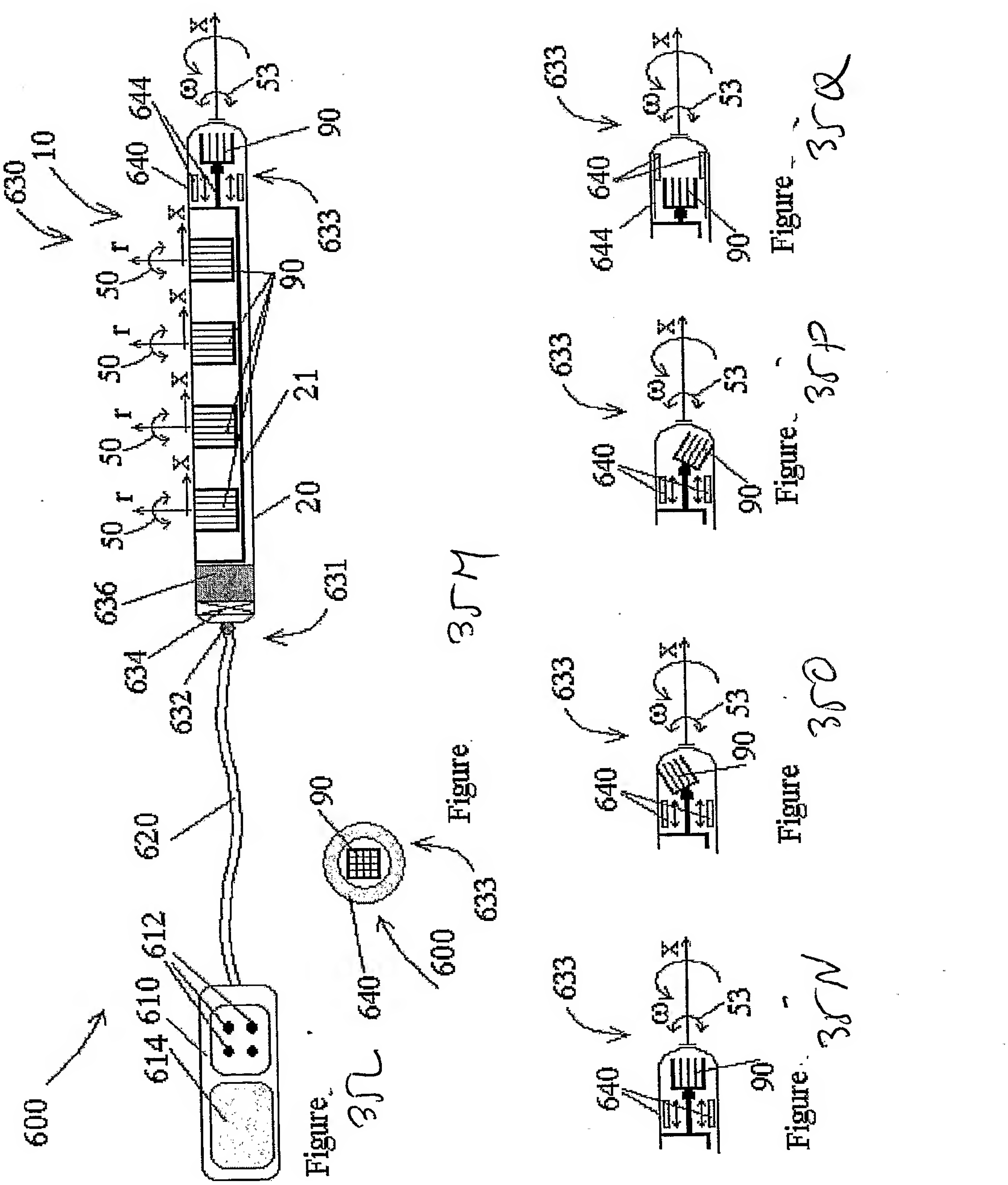


Figure 35J


600
610
612
614
620
632
634
636
631
630
10
640
644
90
633
50
r
x
21
20
53
ω
Figure 35L
35M
Figure 35N
Figure 35O
Figure 35P
Figure 35Q

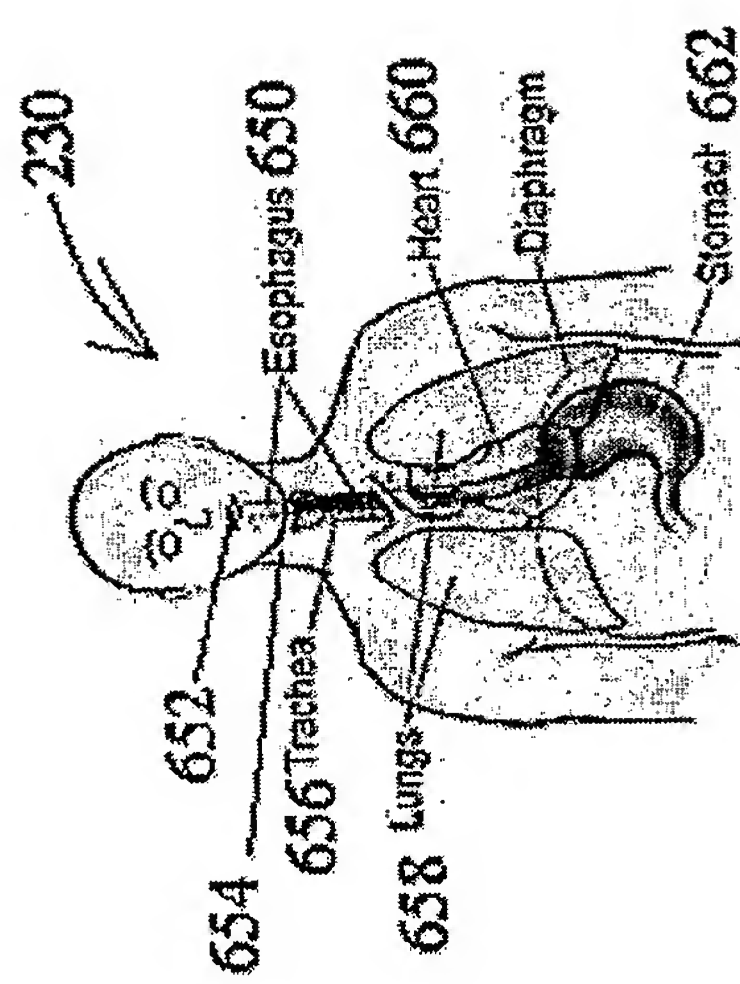

230
Esophagus 650
Heart 660
Diaphragm
Stomach 662
652
654
656 Trachea
Lungs
658

Figure 3JR

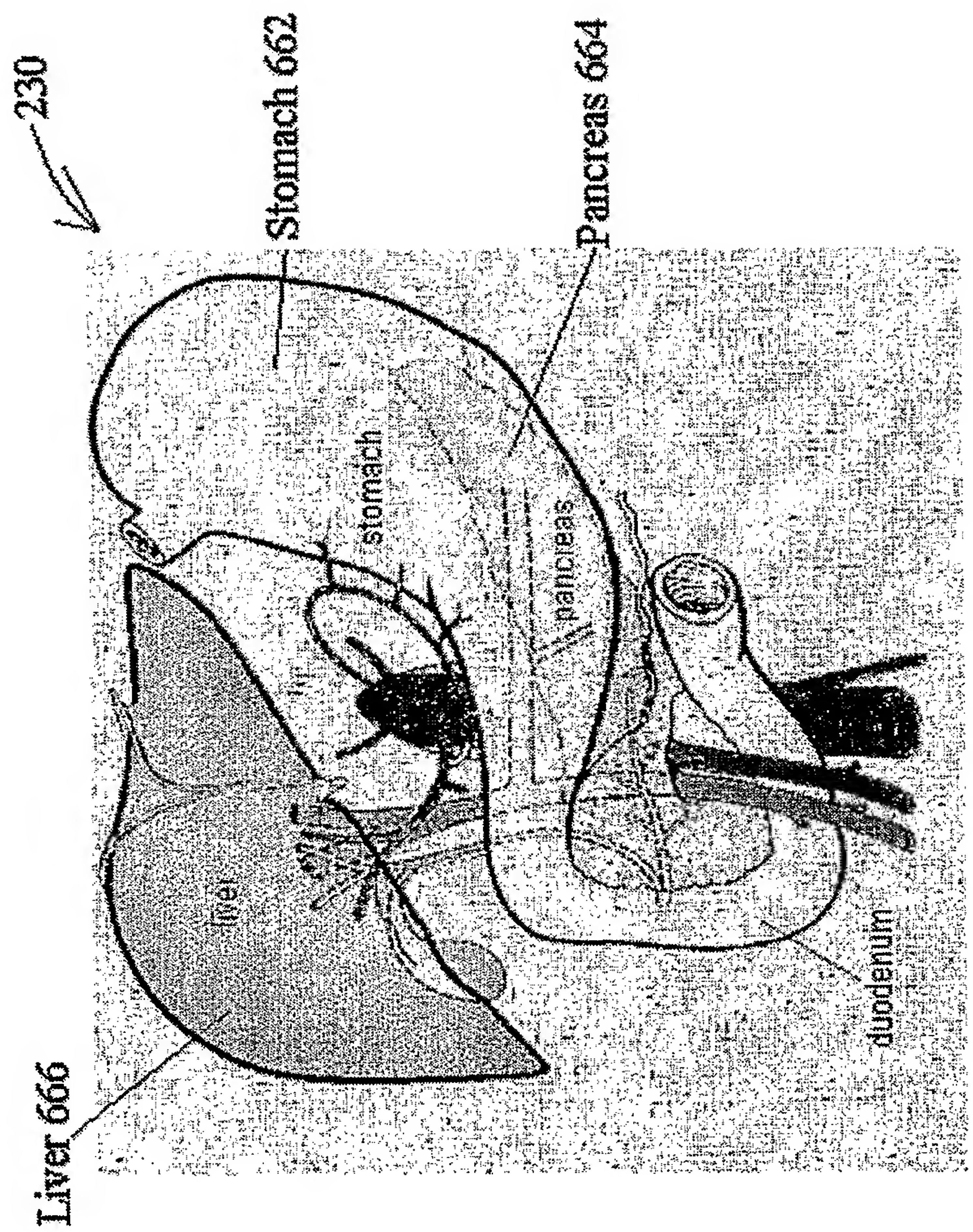

230
Stomach 662
Pancreas 664
Liver 666
liver
stomach
pancreas
duodenum

Figure 35S.

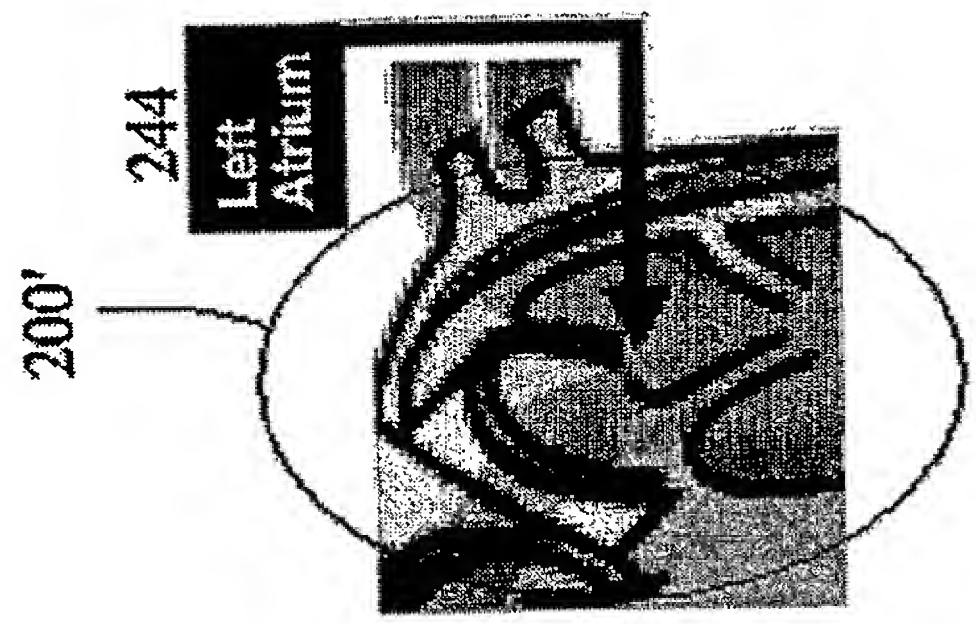


Figure 36C

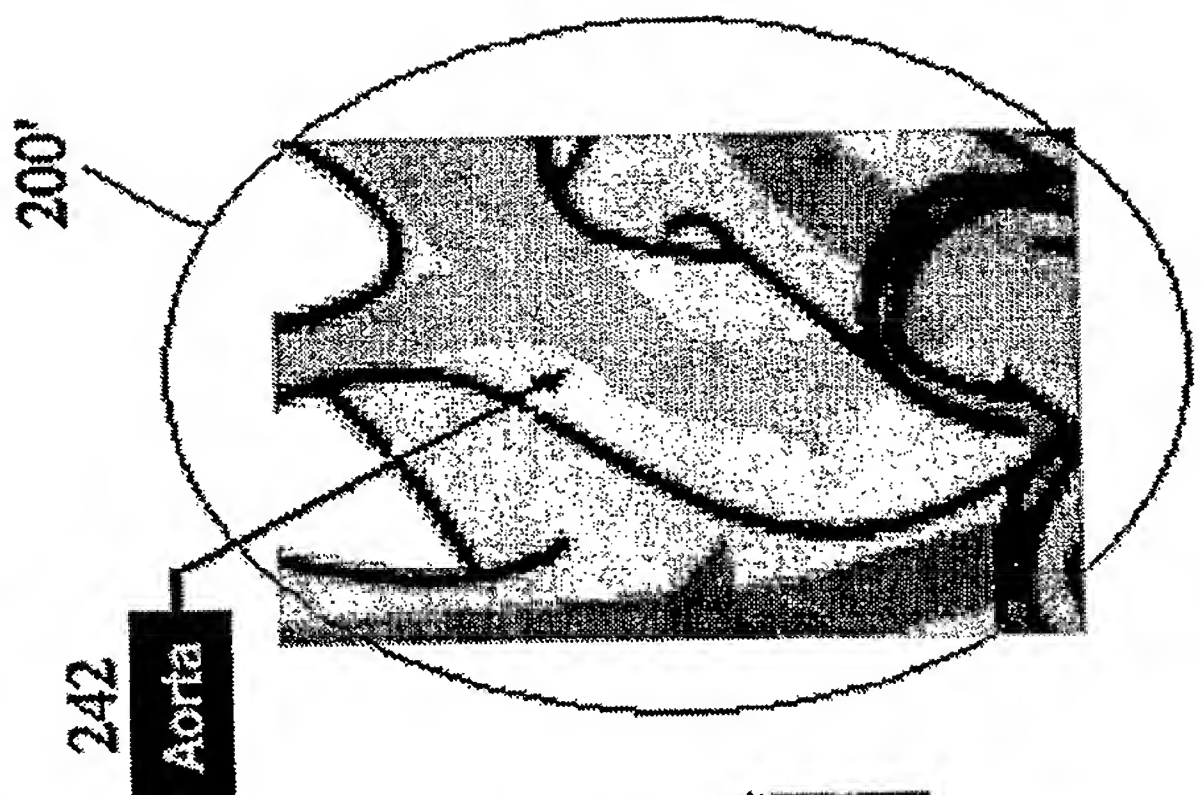


Figure 36B

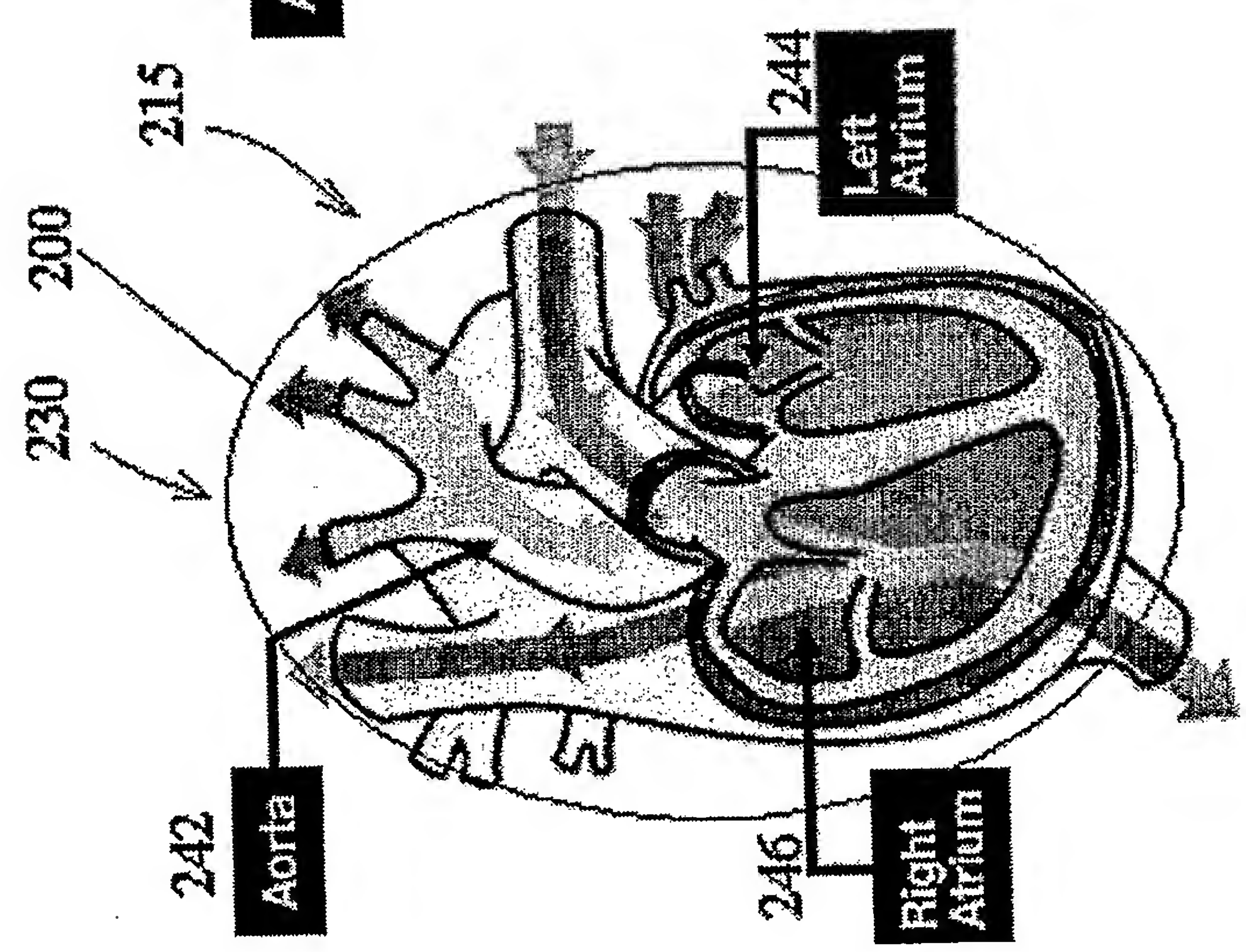


Figure 36A

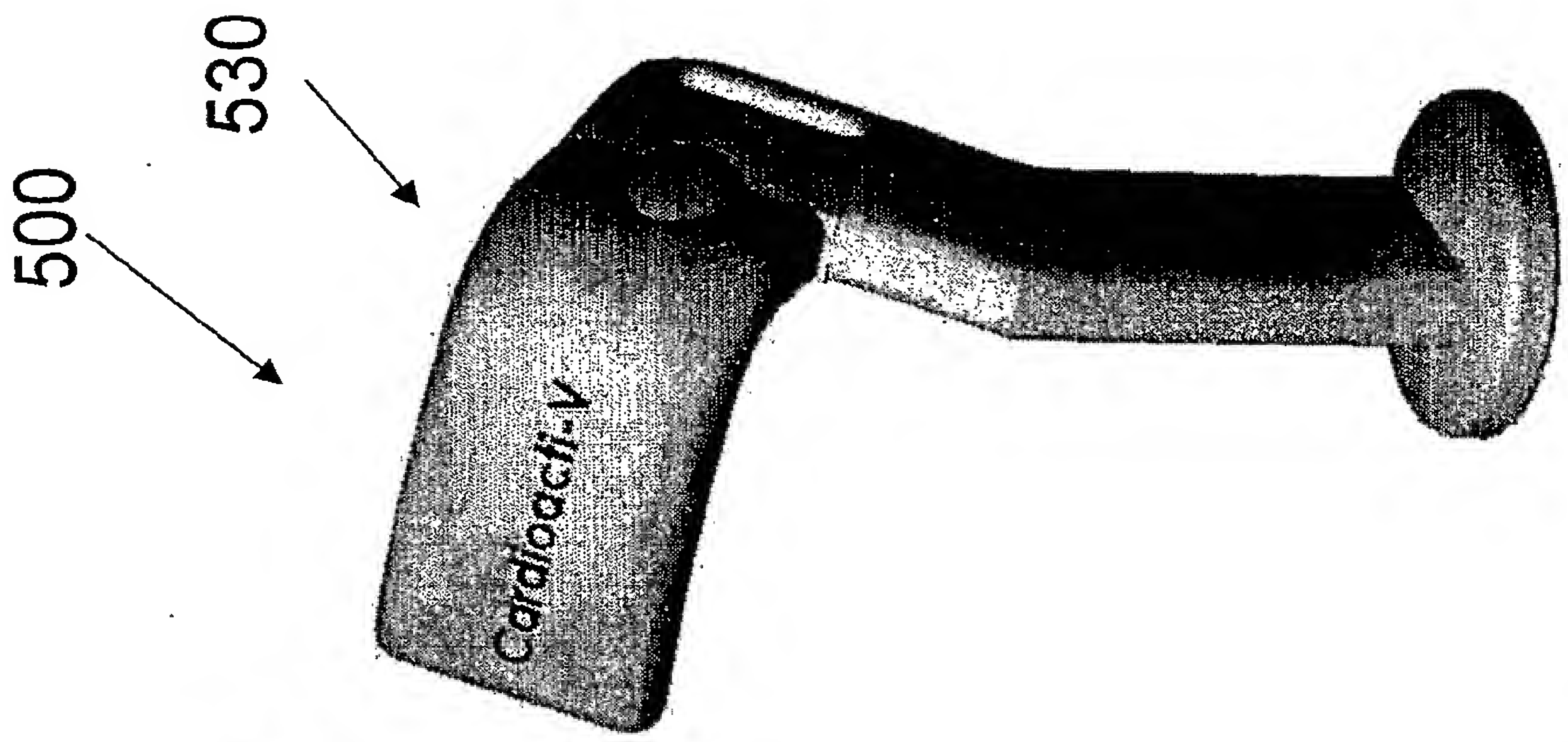


Figure 37C

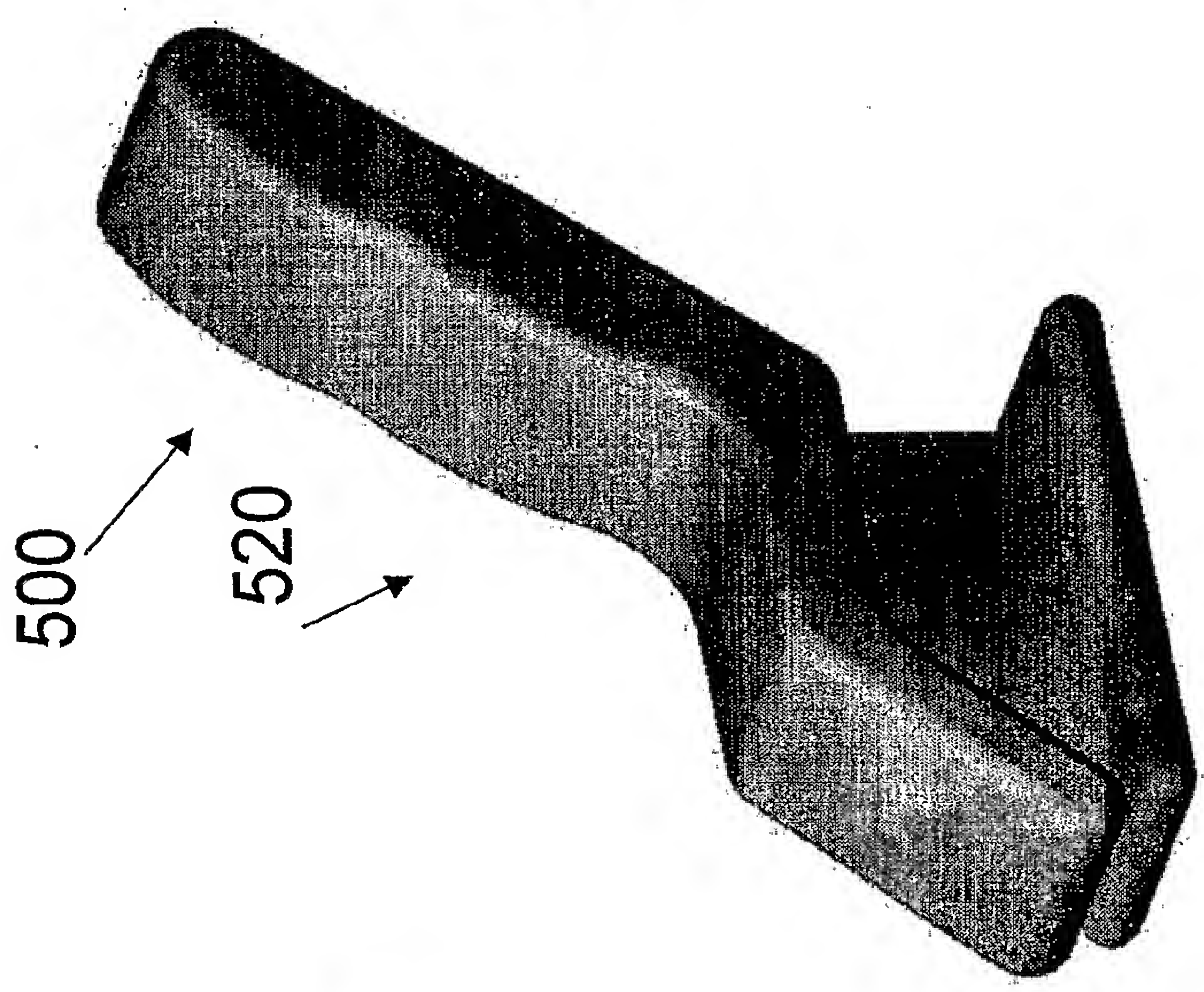


Figure 37B

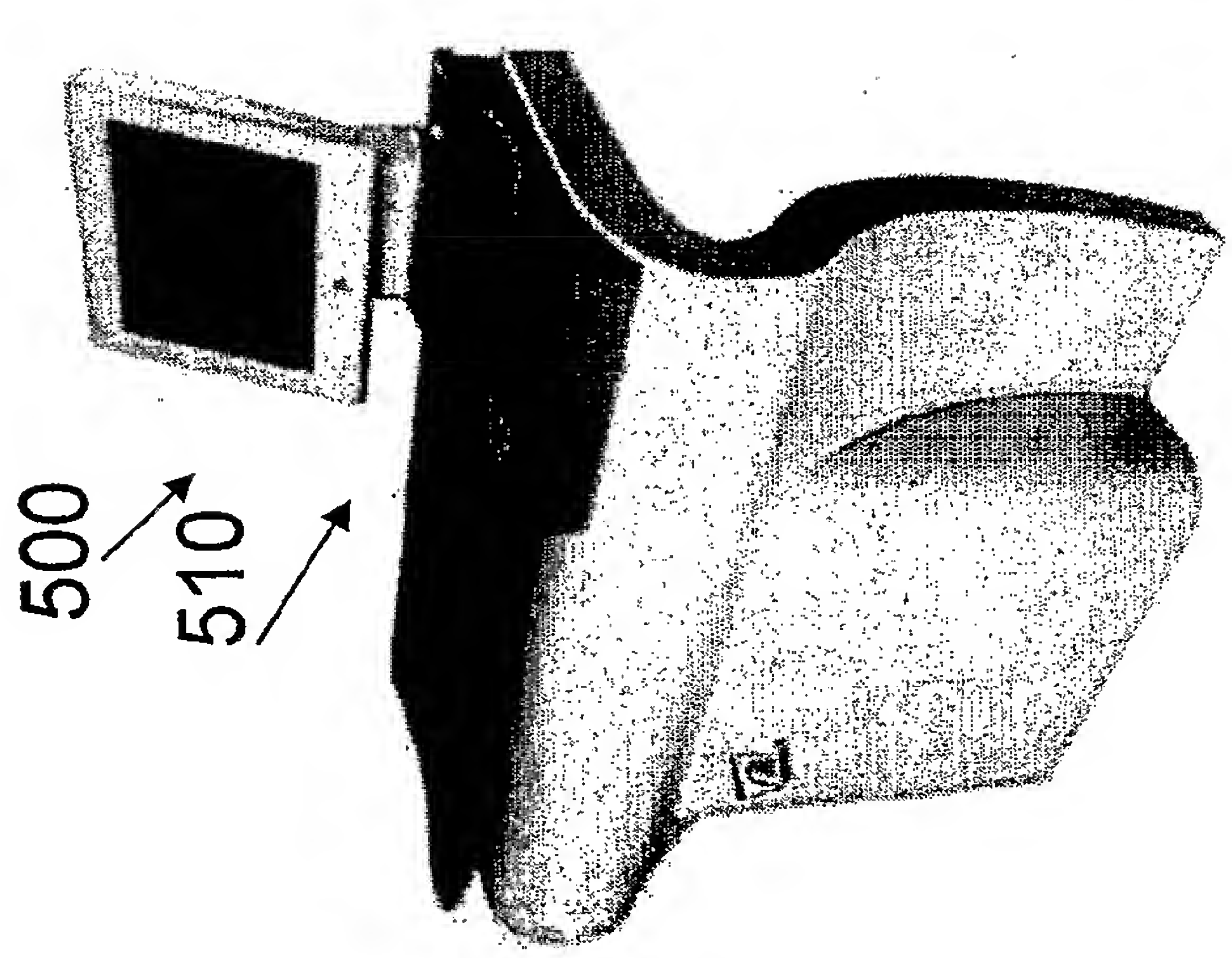


Figure 37A

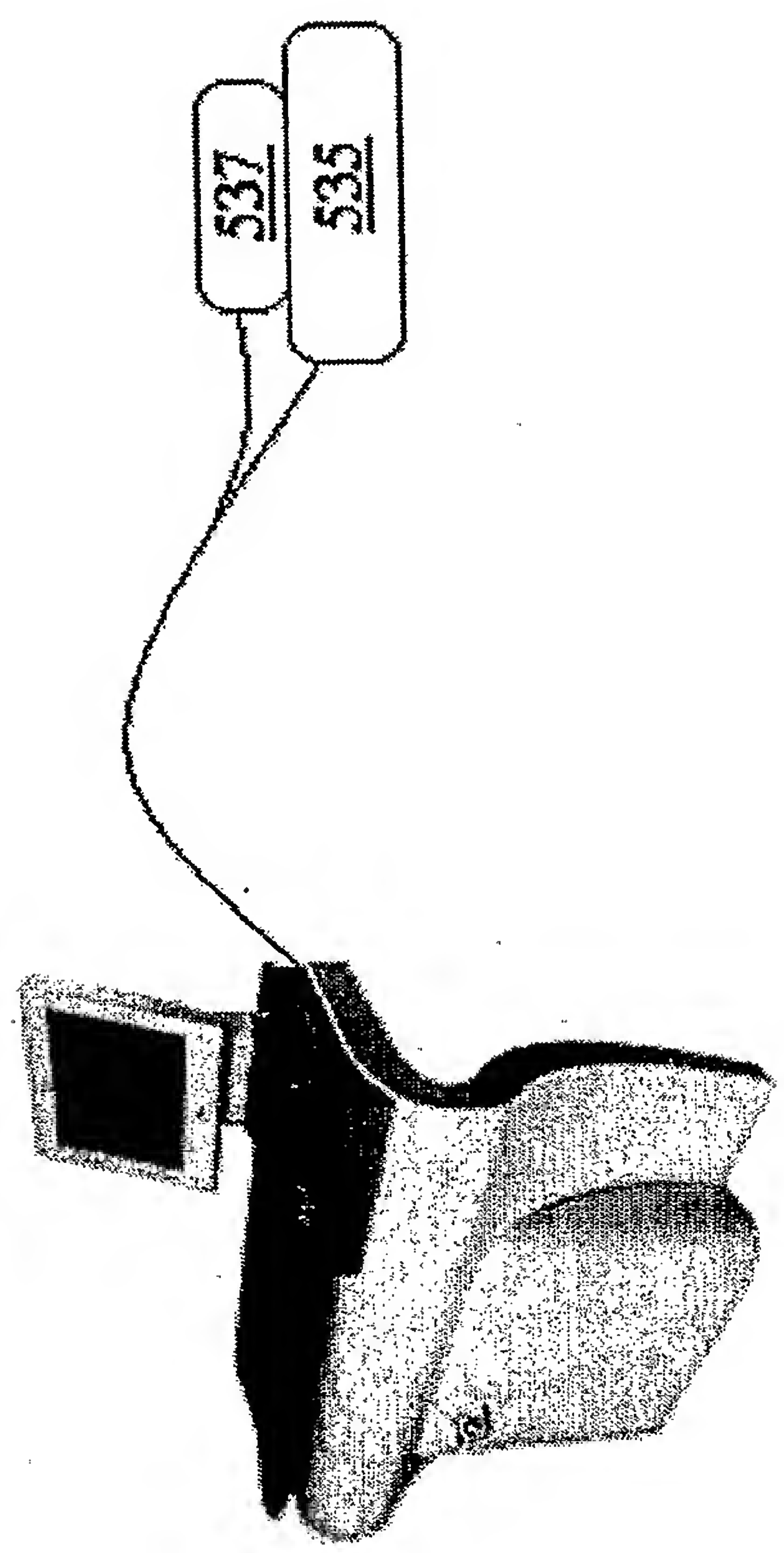


Figure 37D

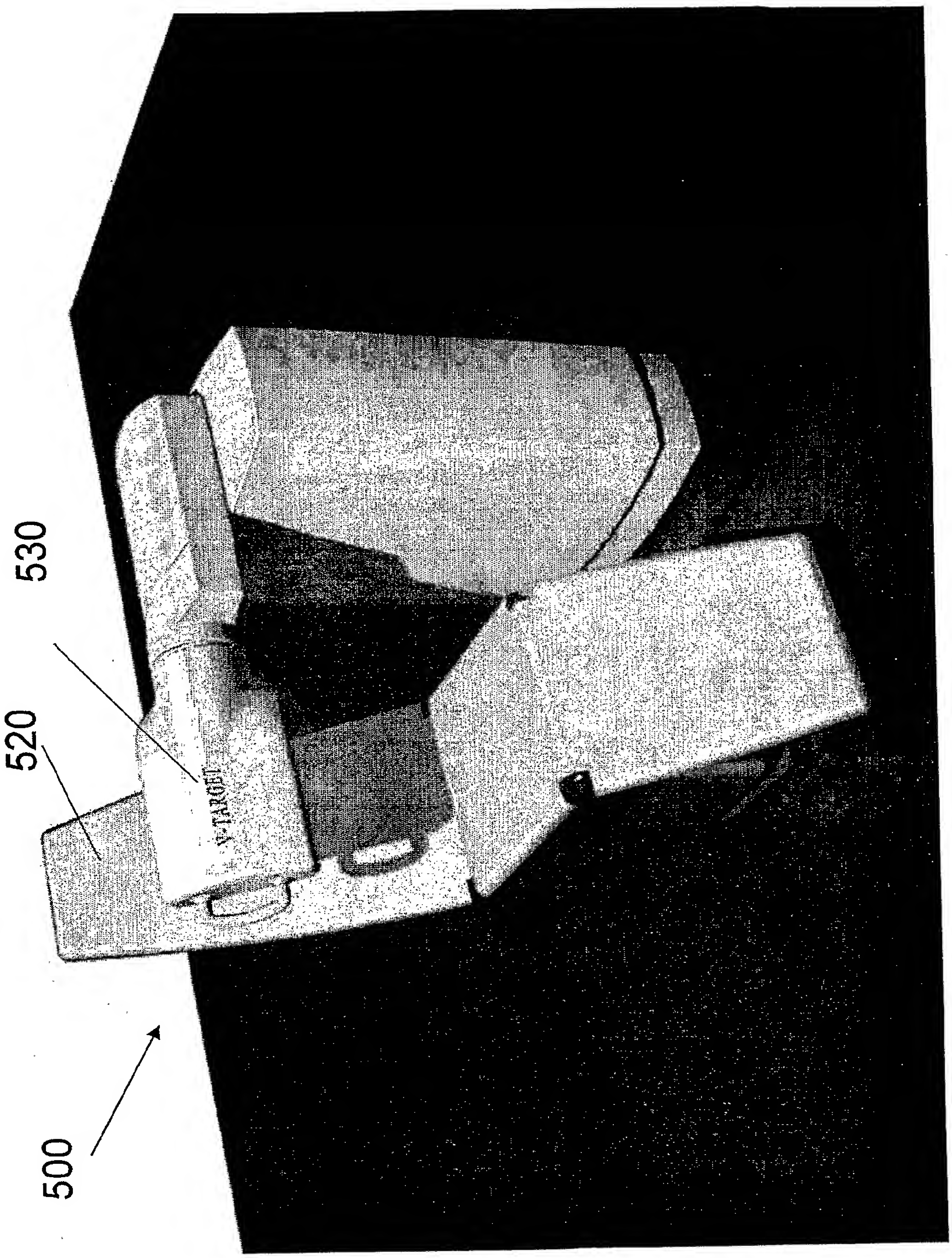


Figure 38

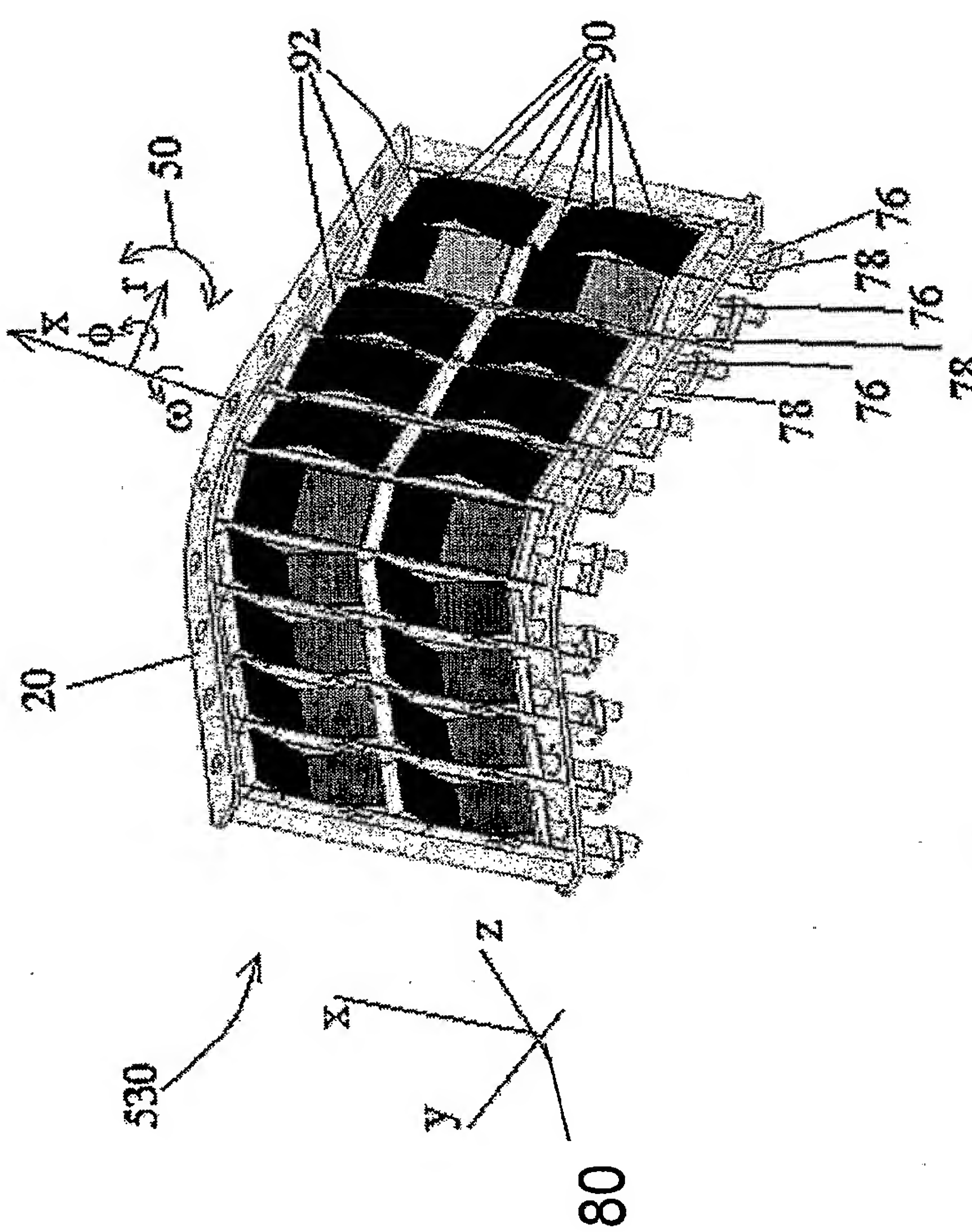


Figure 39A

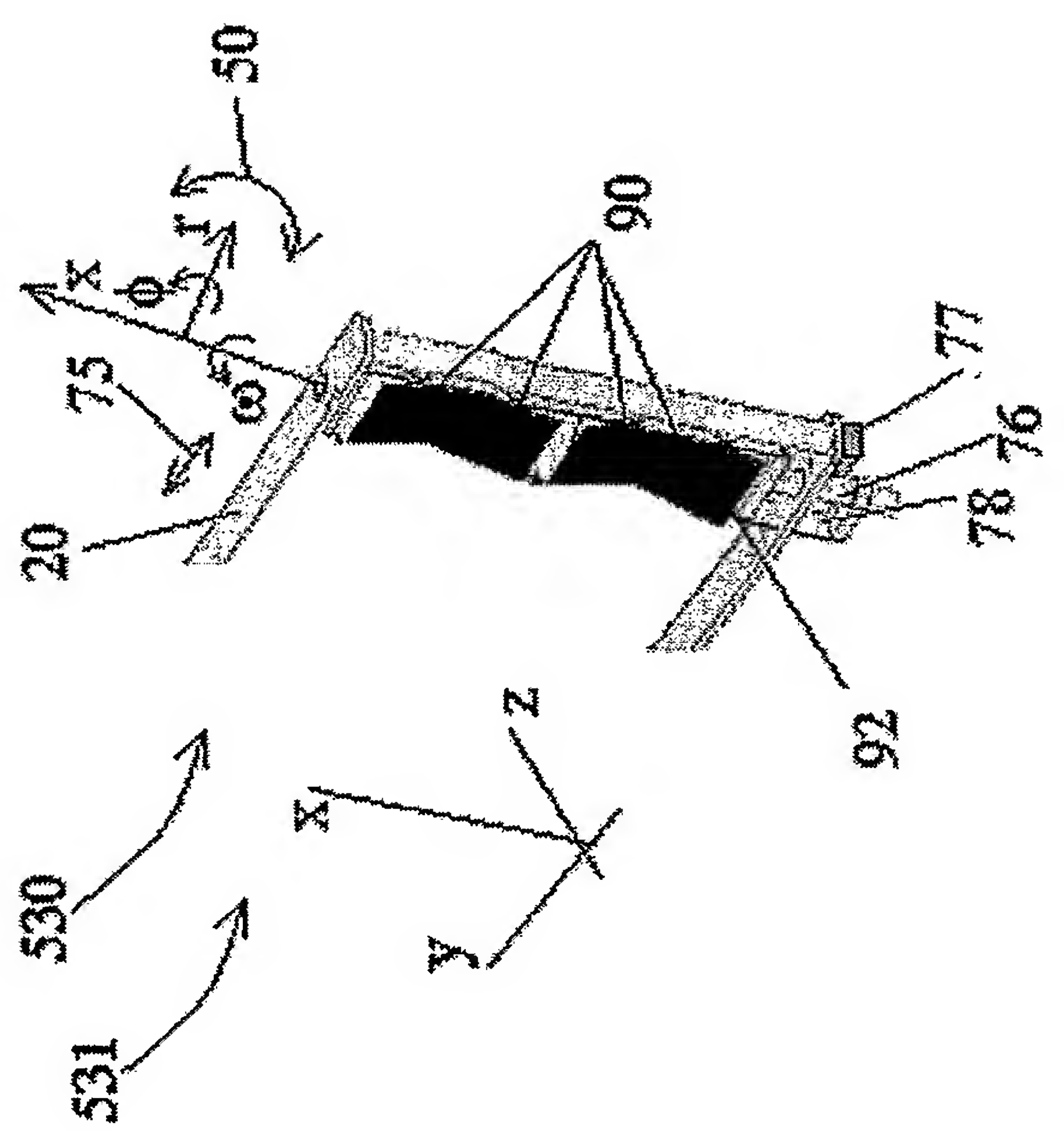


Figure 32B

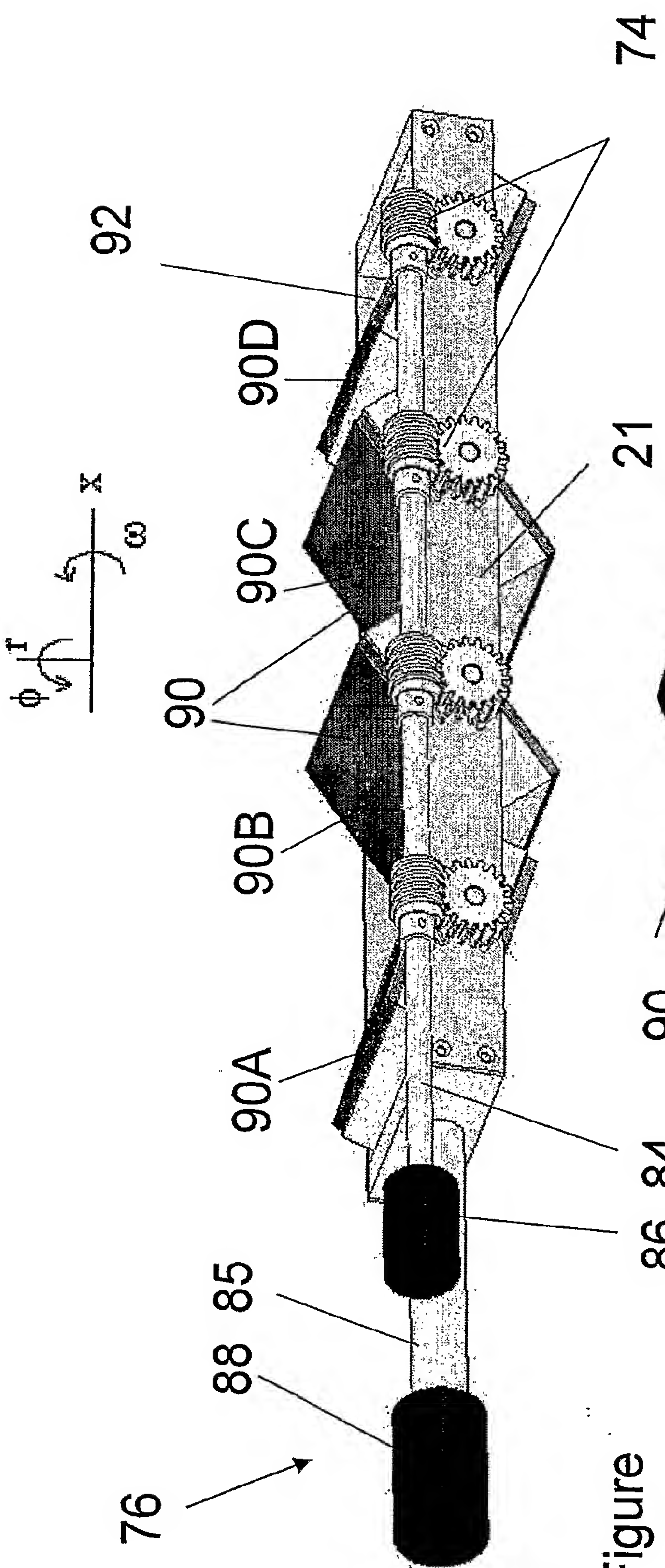


Figure 40A

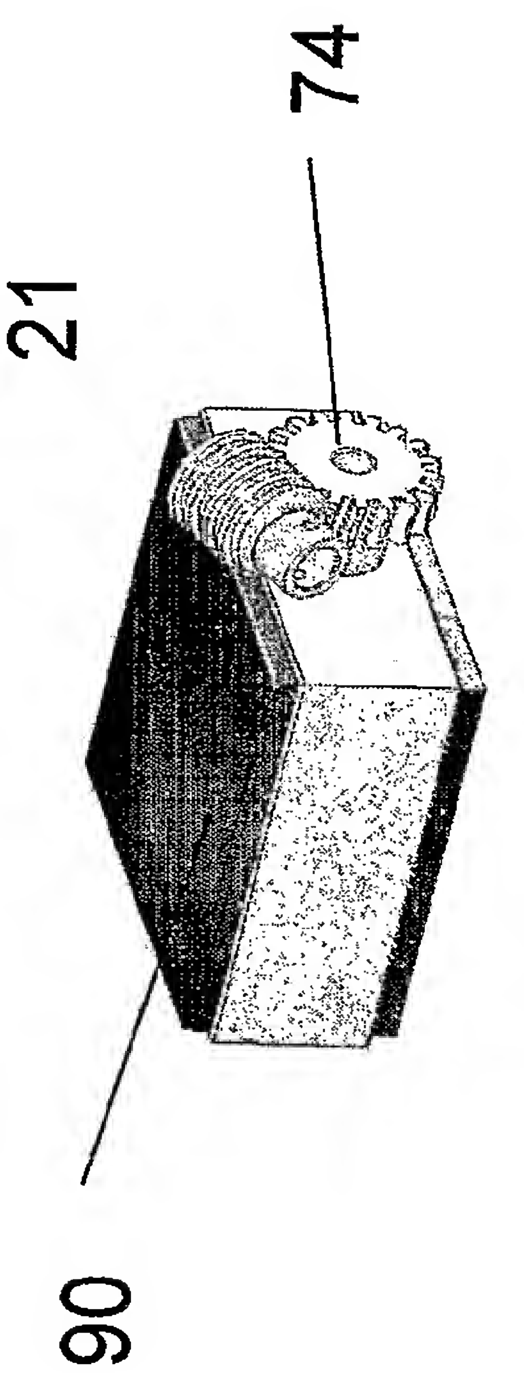


Figure 40B

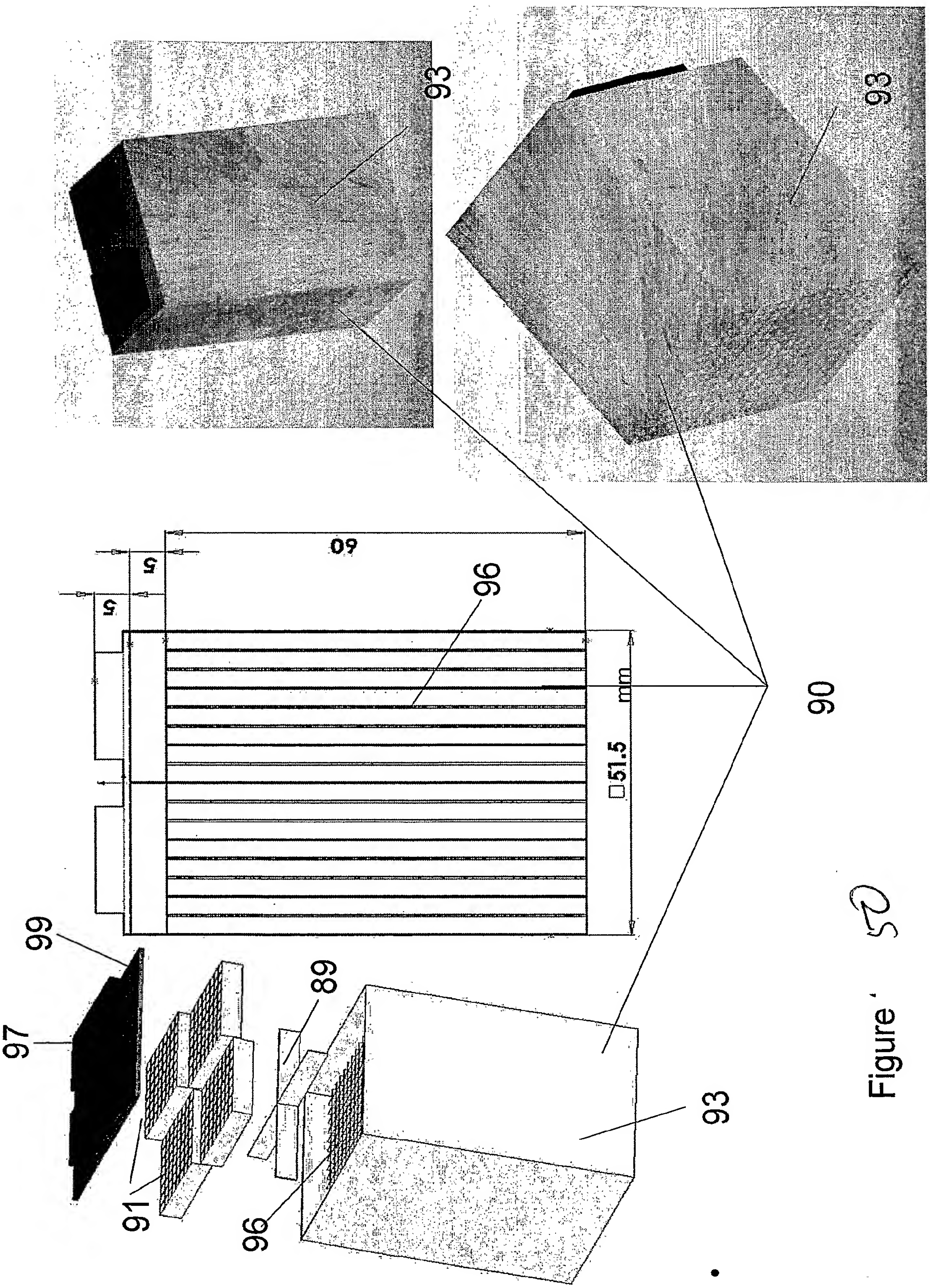


Figure 52

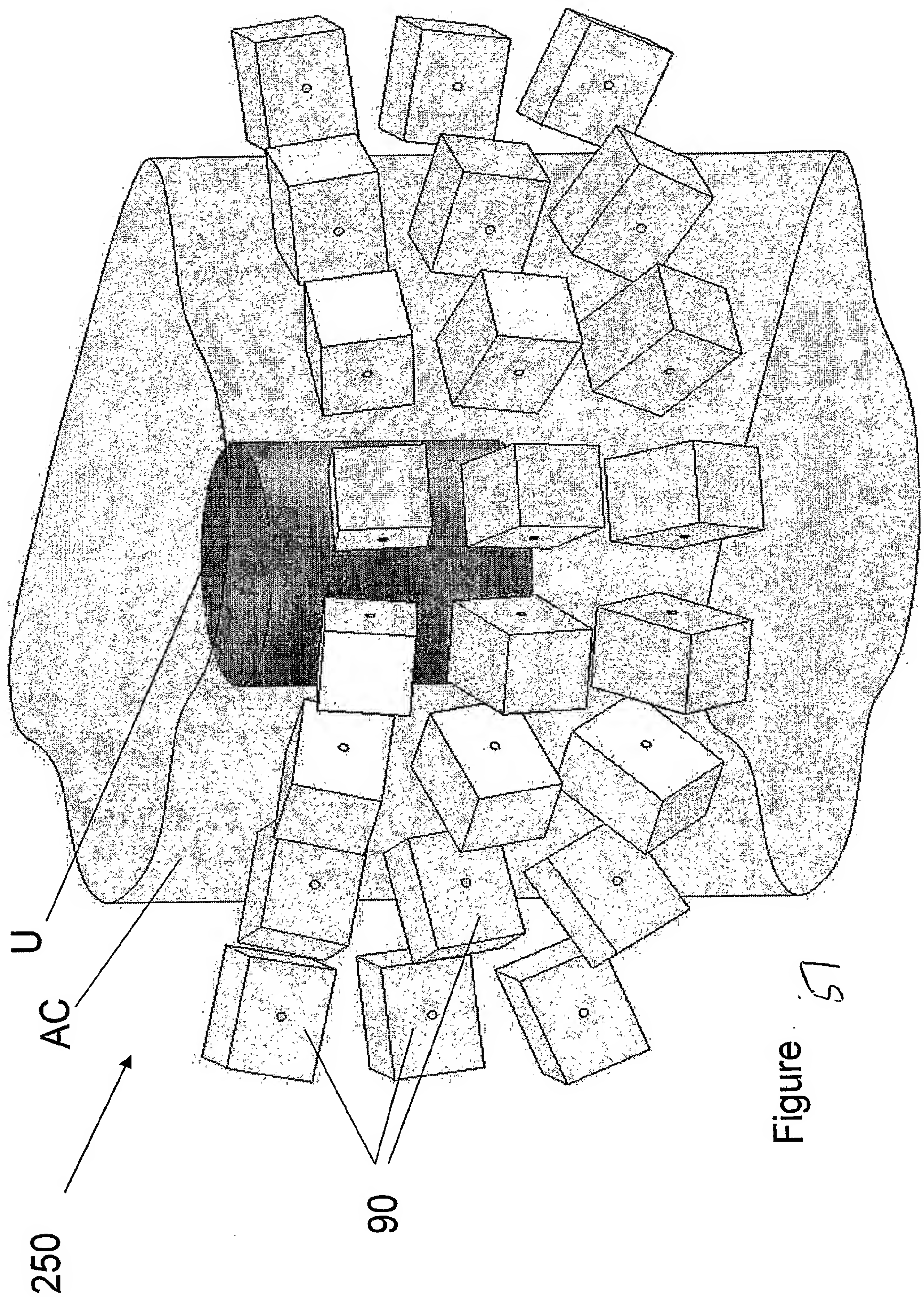


Figure 57

Design Elements

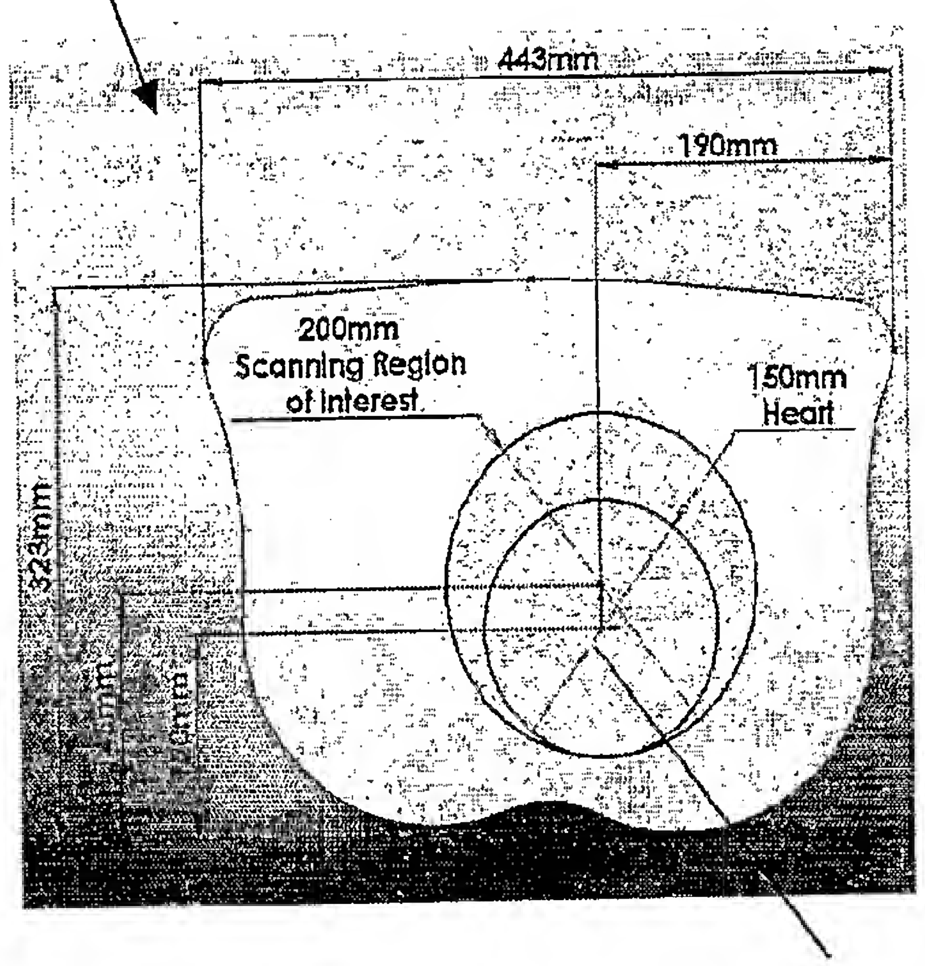


Figure 52D

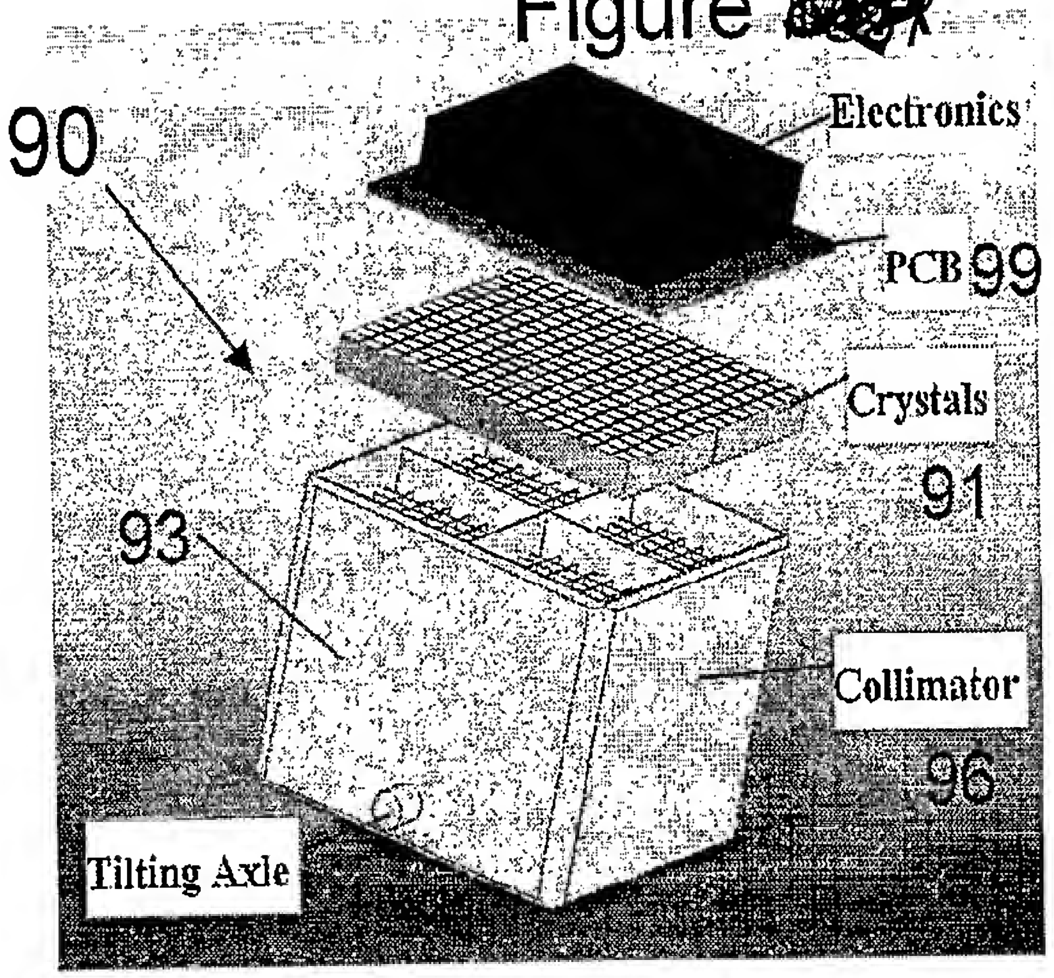


Figure 52A

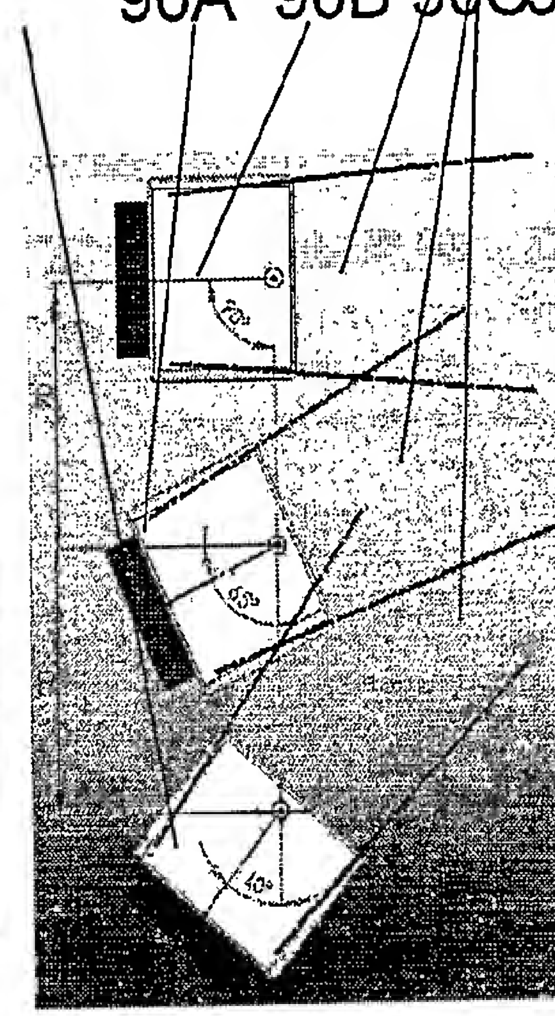


Figure 52C

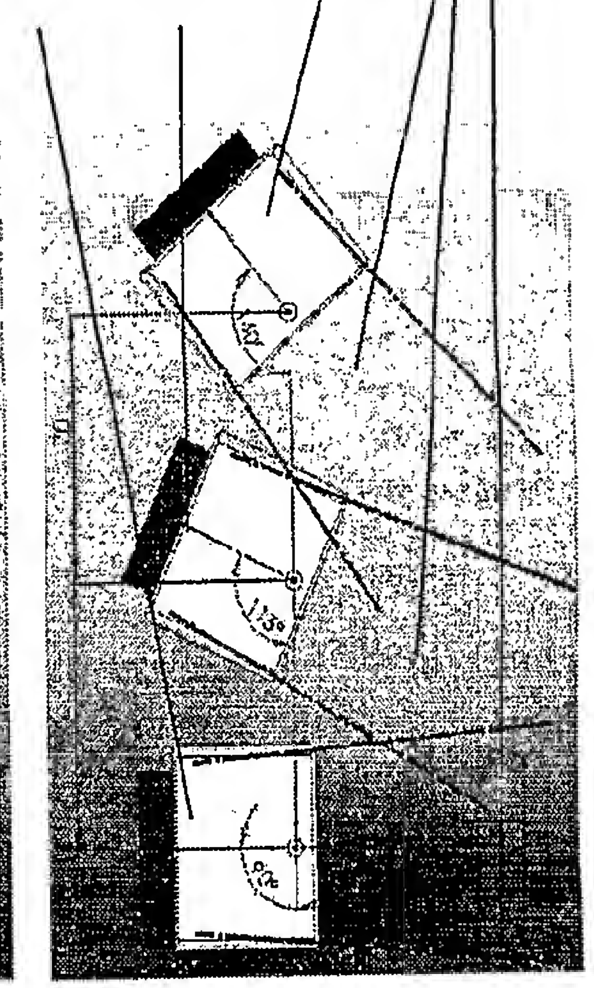


Figure 52B

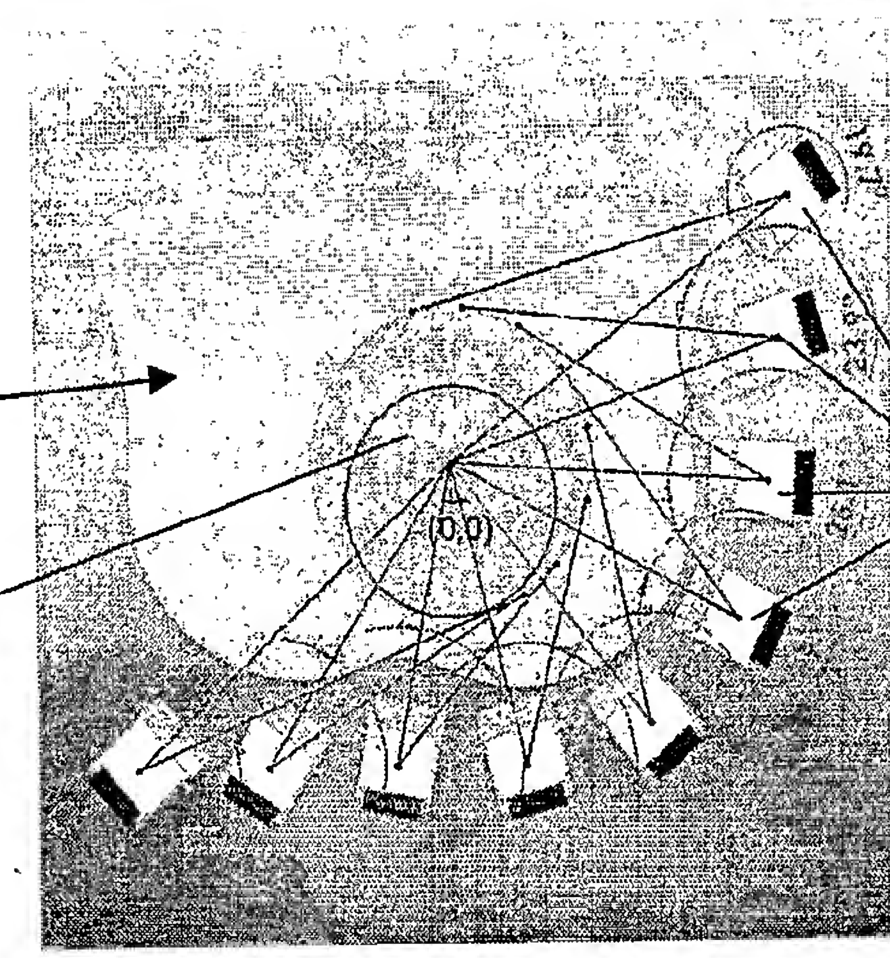


Figure 52E

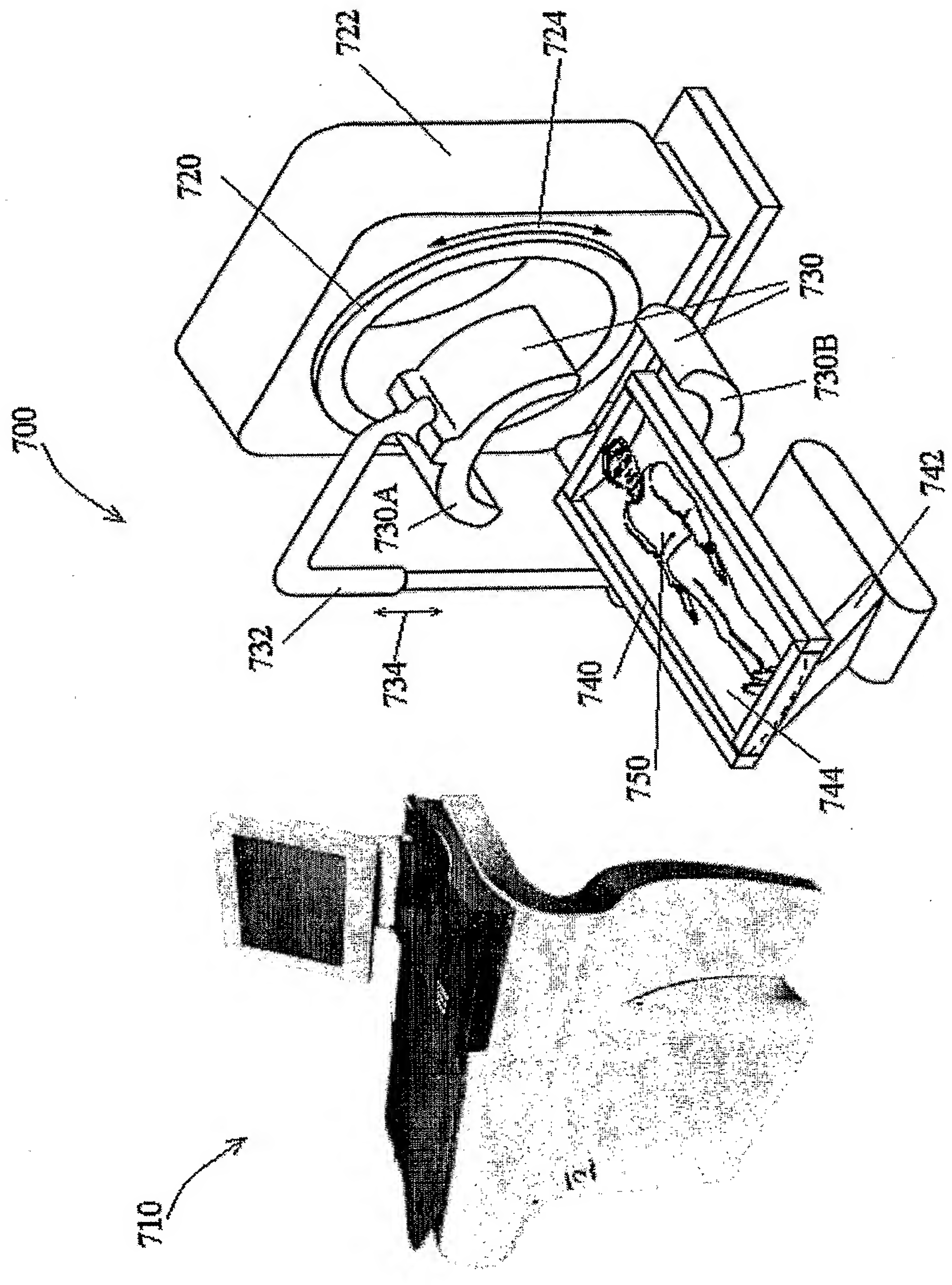


Figure 53

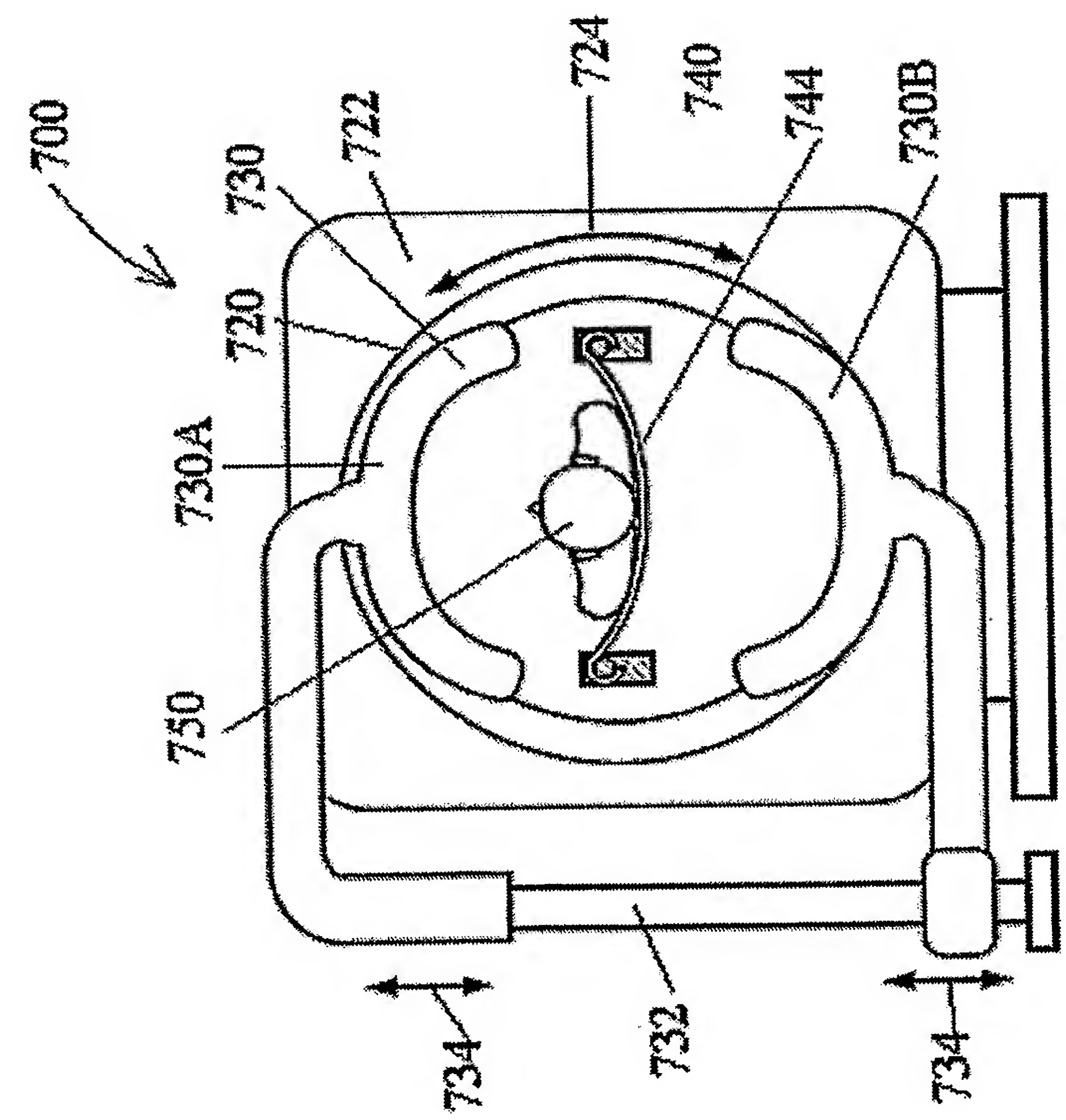


Figure 54

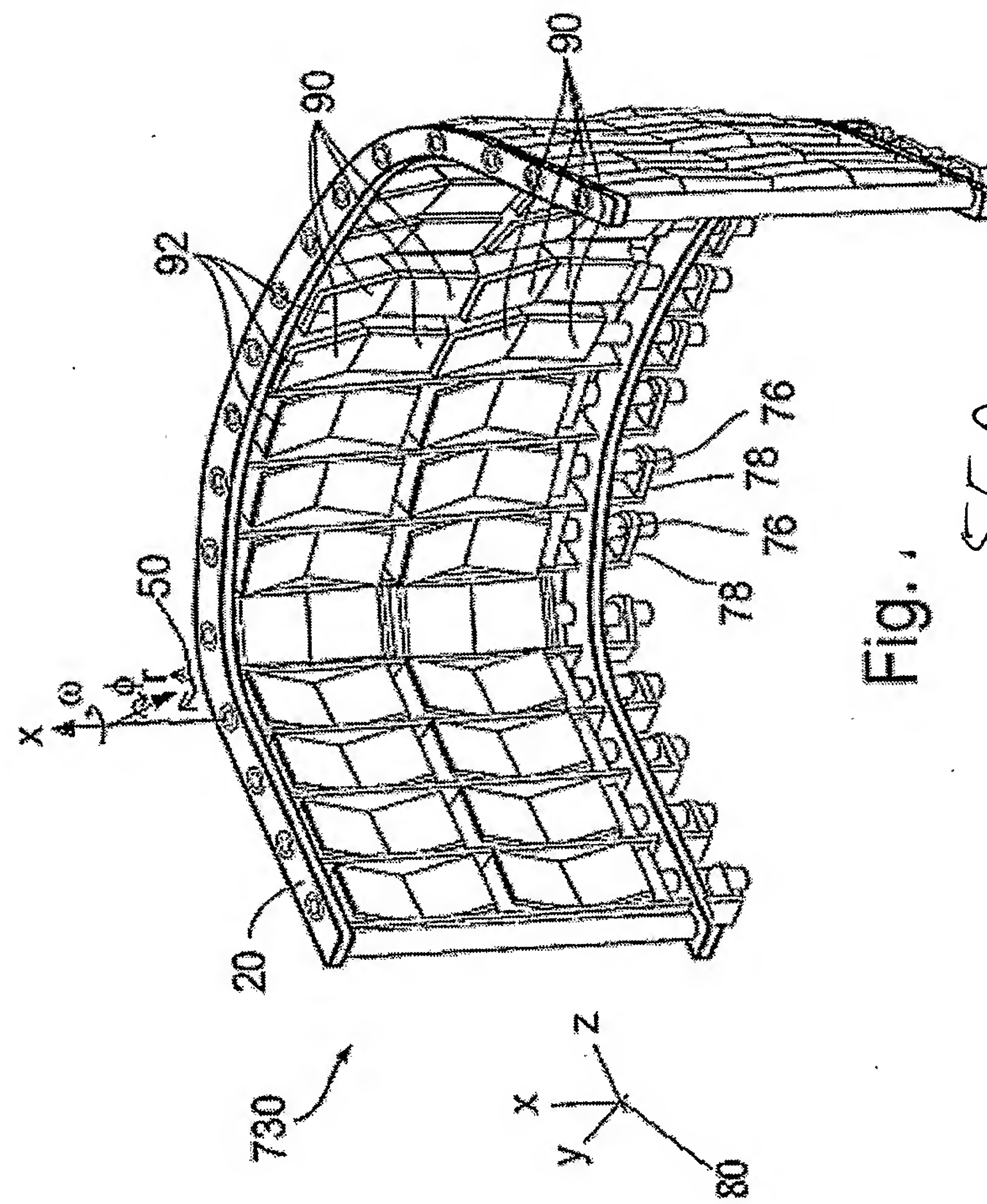


Fig. 55A

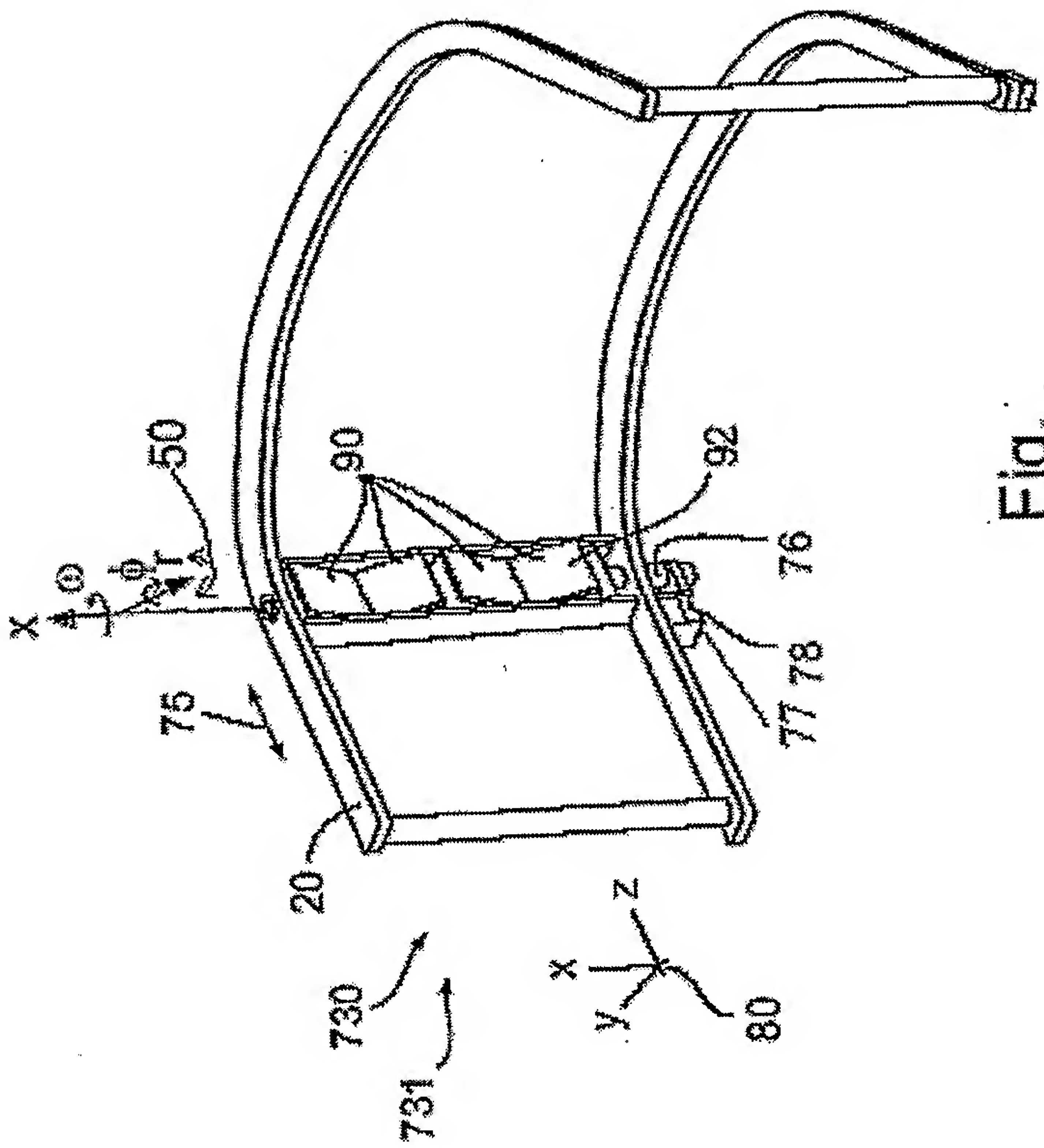


Fig. 55B

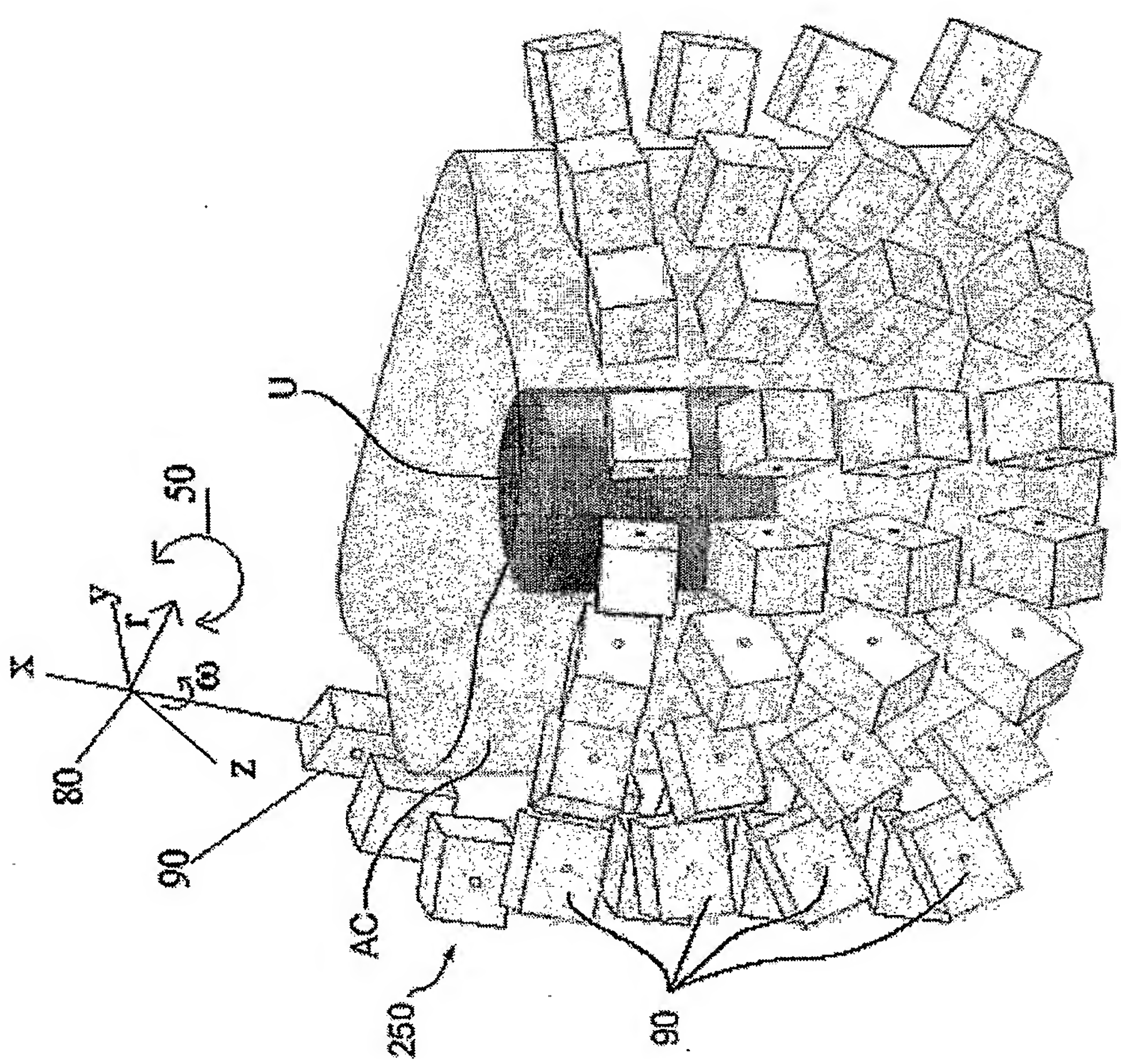


Figure 33C

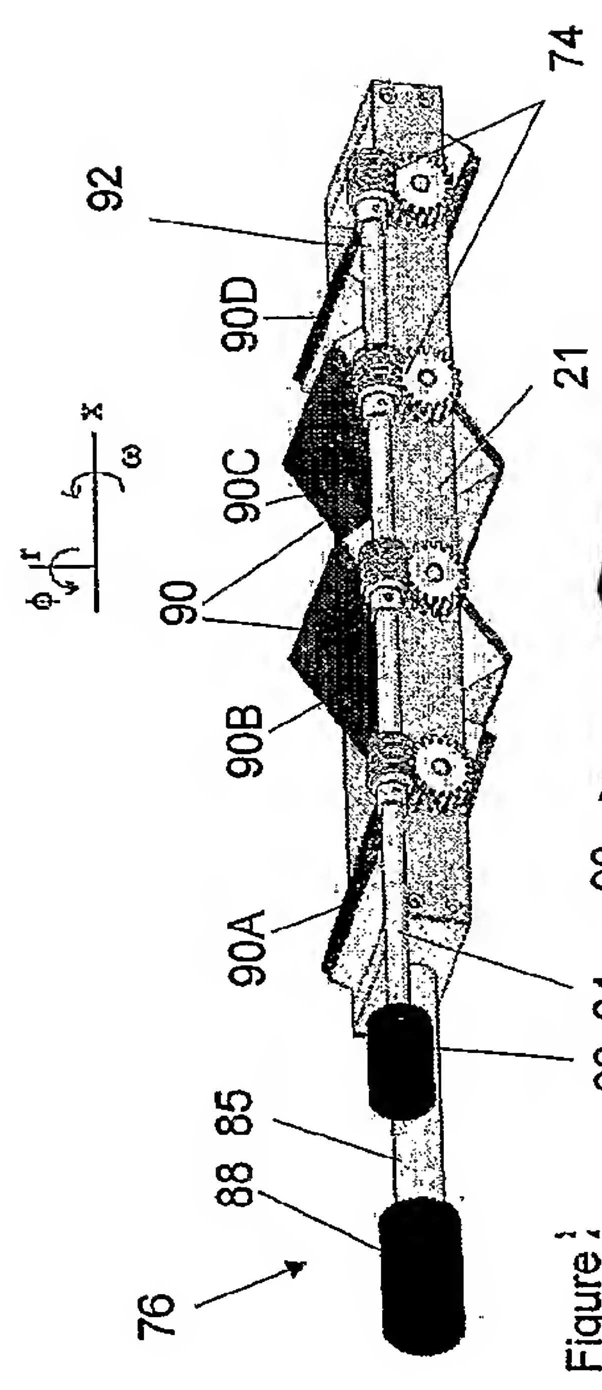


Figure 56A

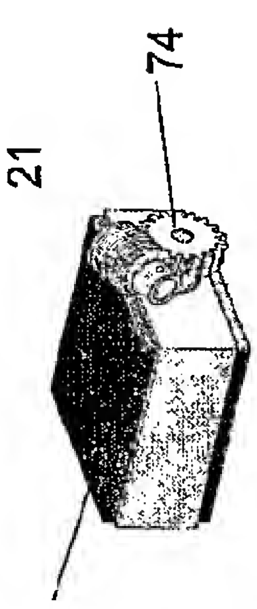


Figure 56B

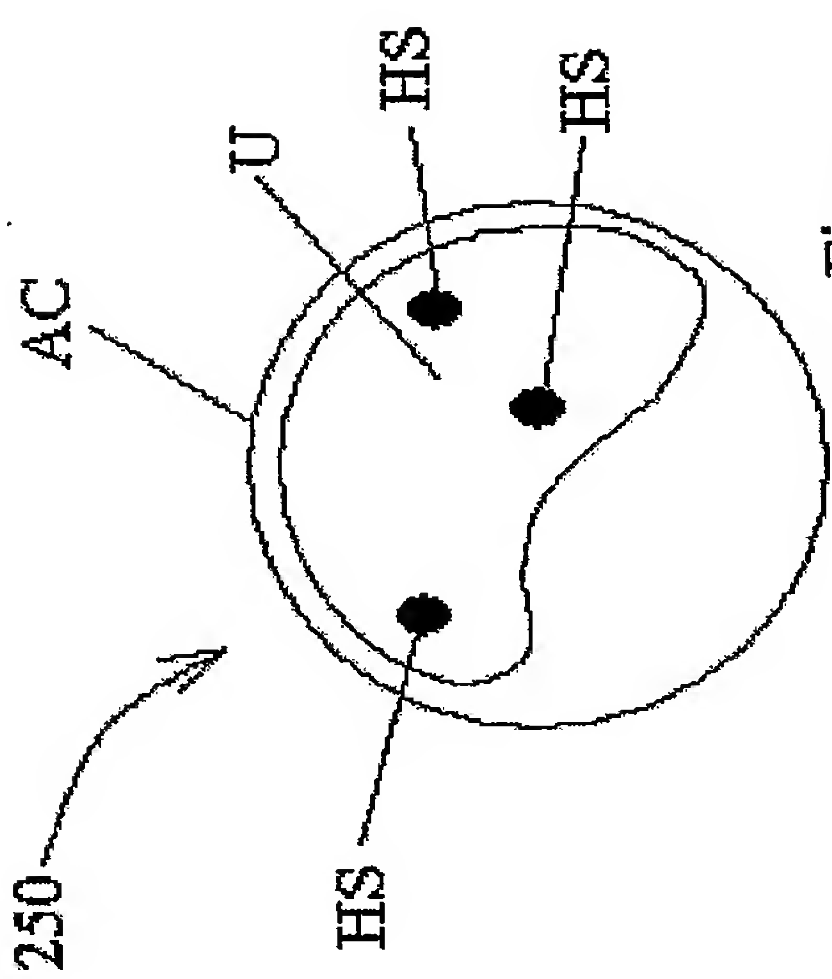


Figure 57B

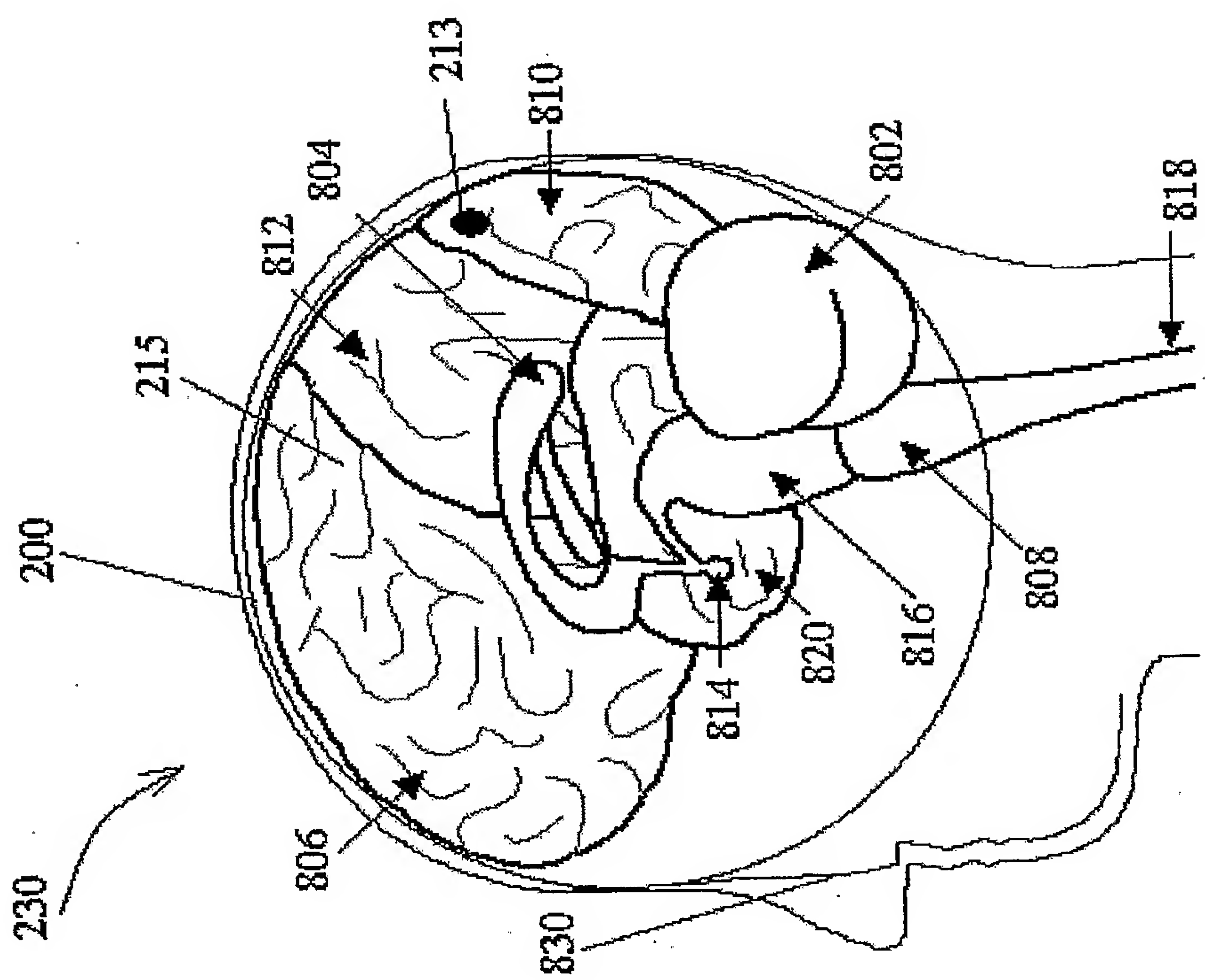


Figure 57A

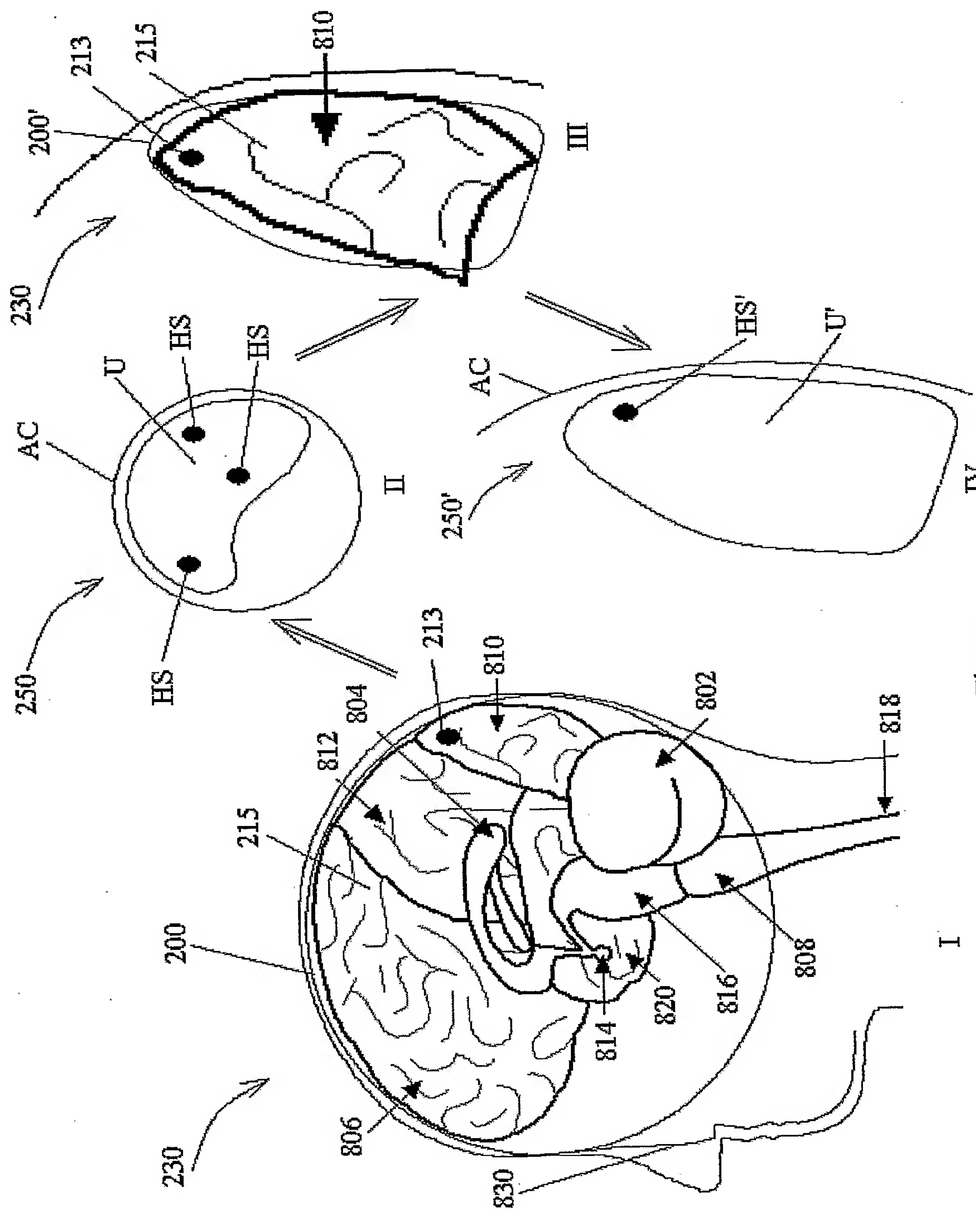

230
200'
213
215
810
III
AC
U
HS
HS
II
HS
250
AC
HS'
U'
IV
250'
213
810
804
812
215
200
802
818
808
816
820
814
806
230
830
I

Figure 58

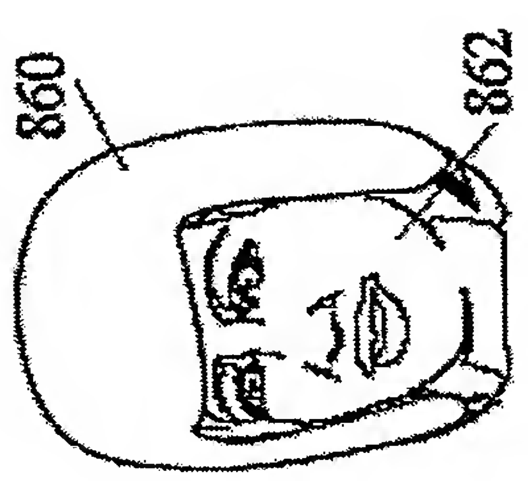


Figure 59A

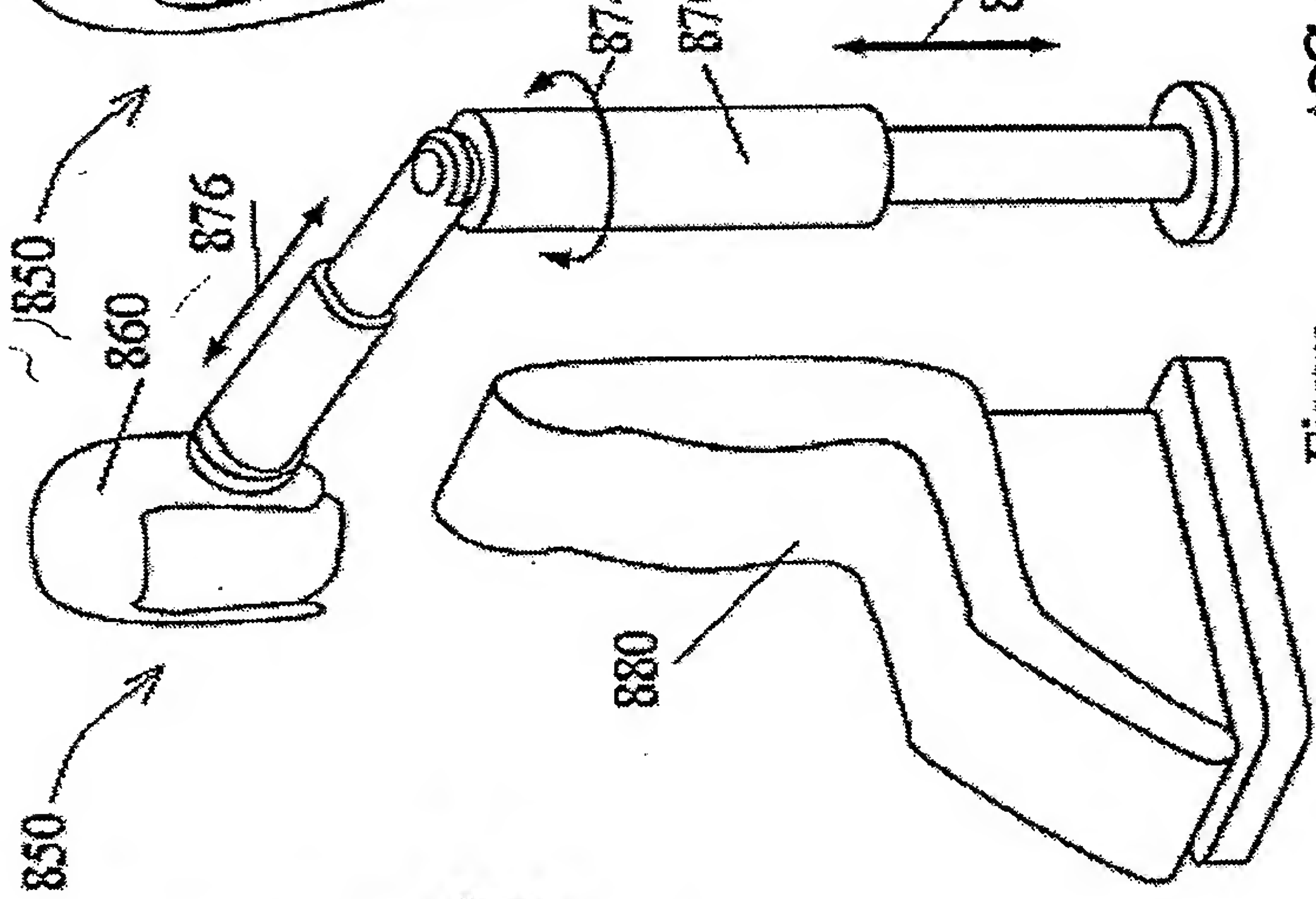


Figure 59B

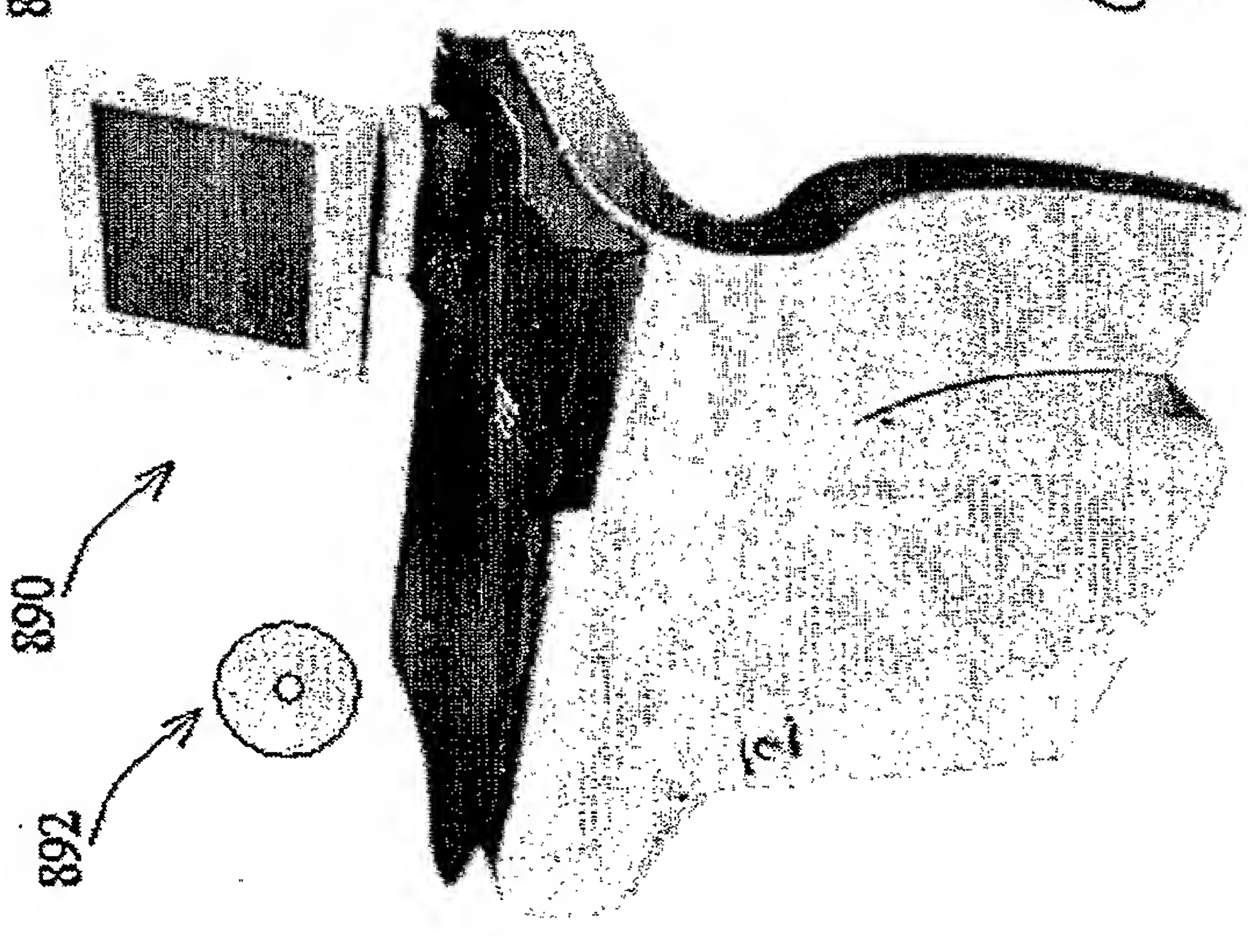


Figure 59C

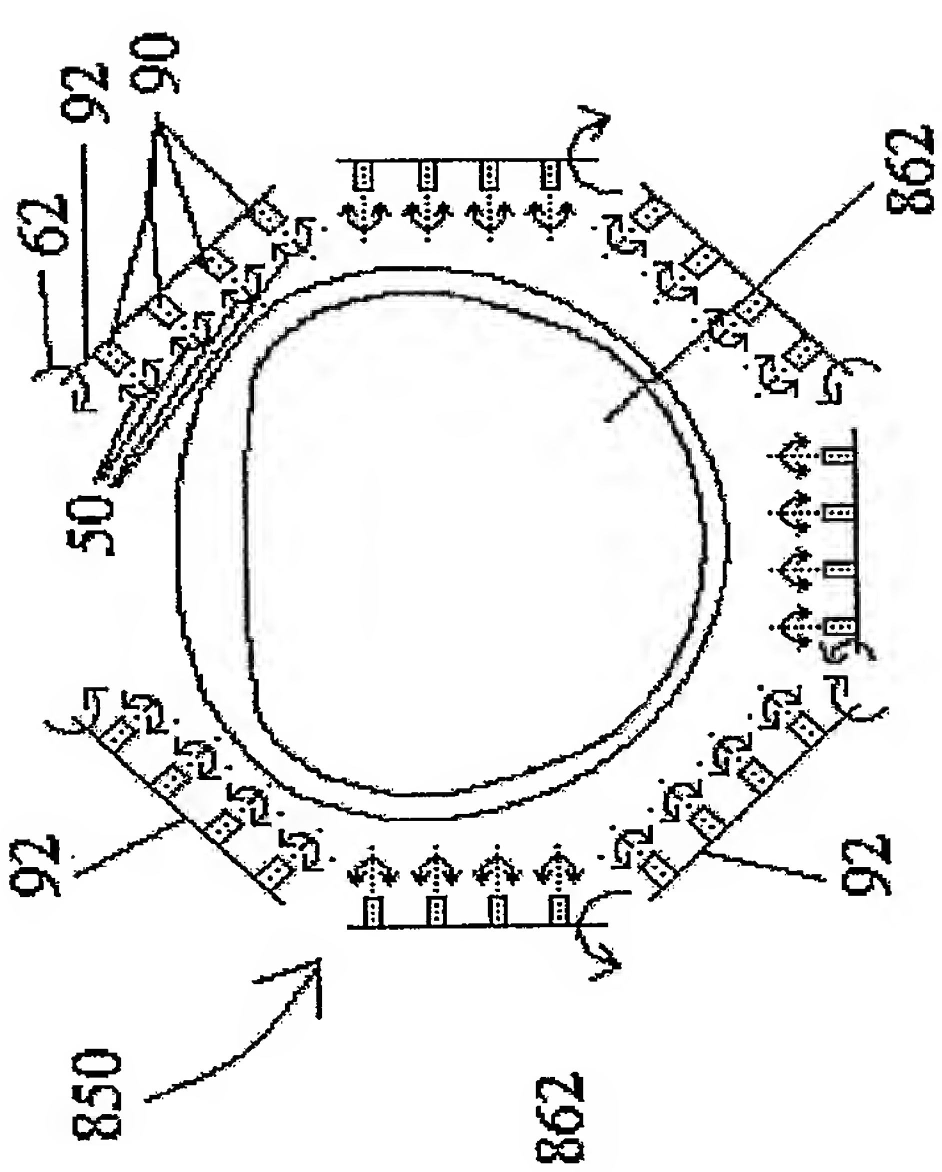


Figure 60B

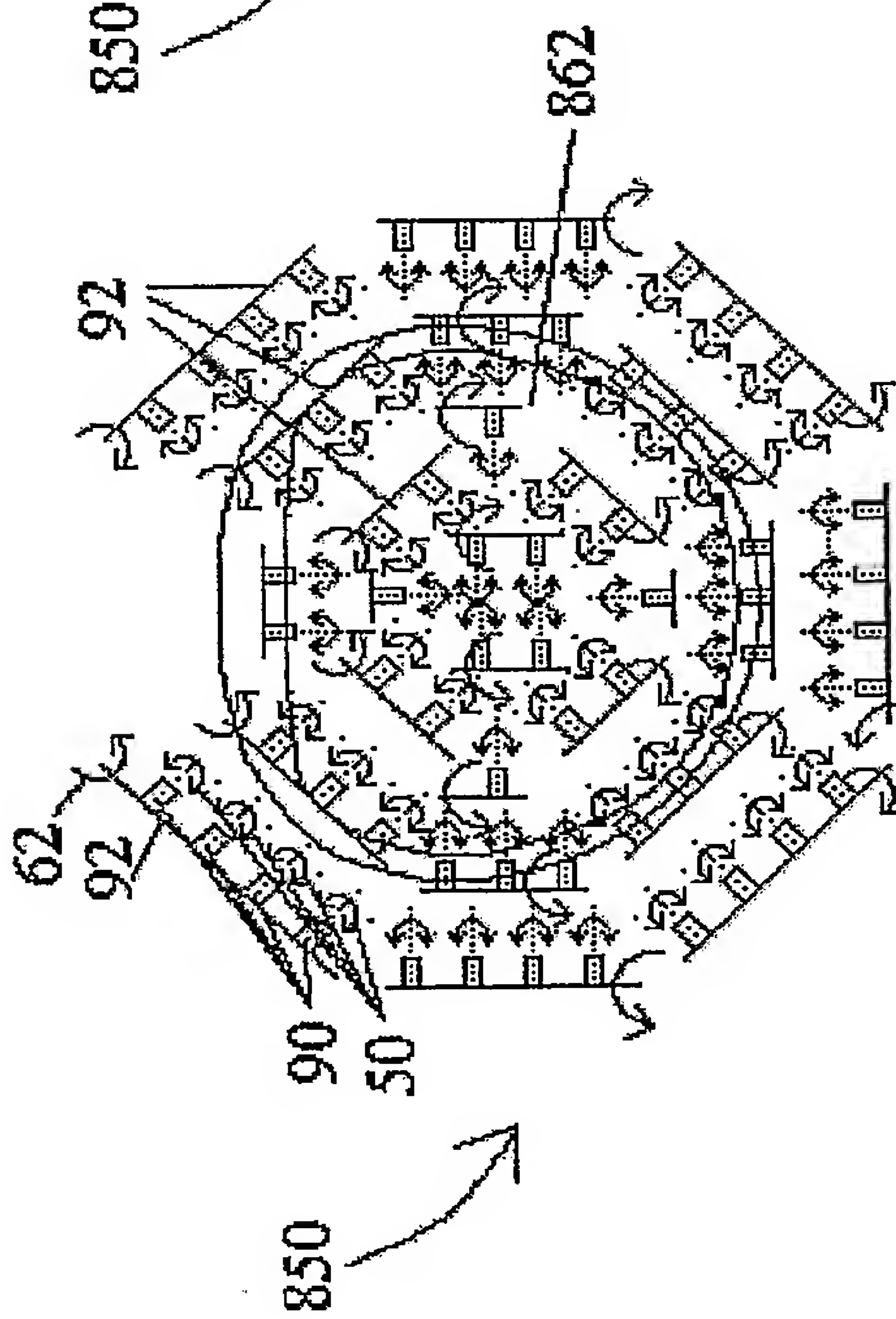


Figure 60C

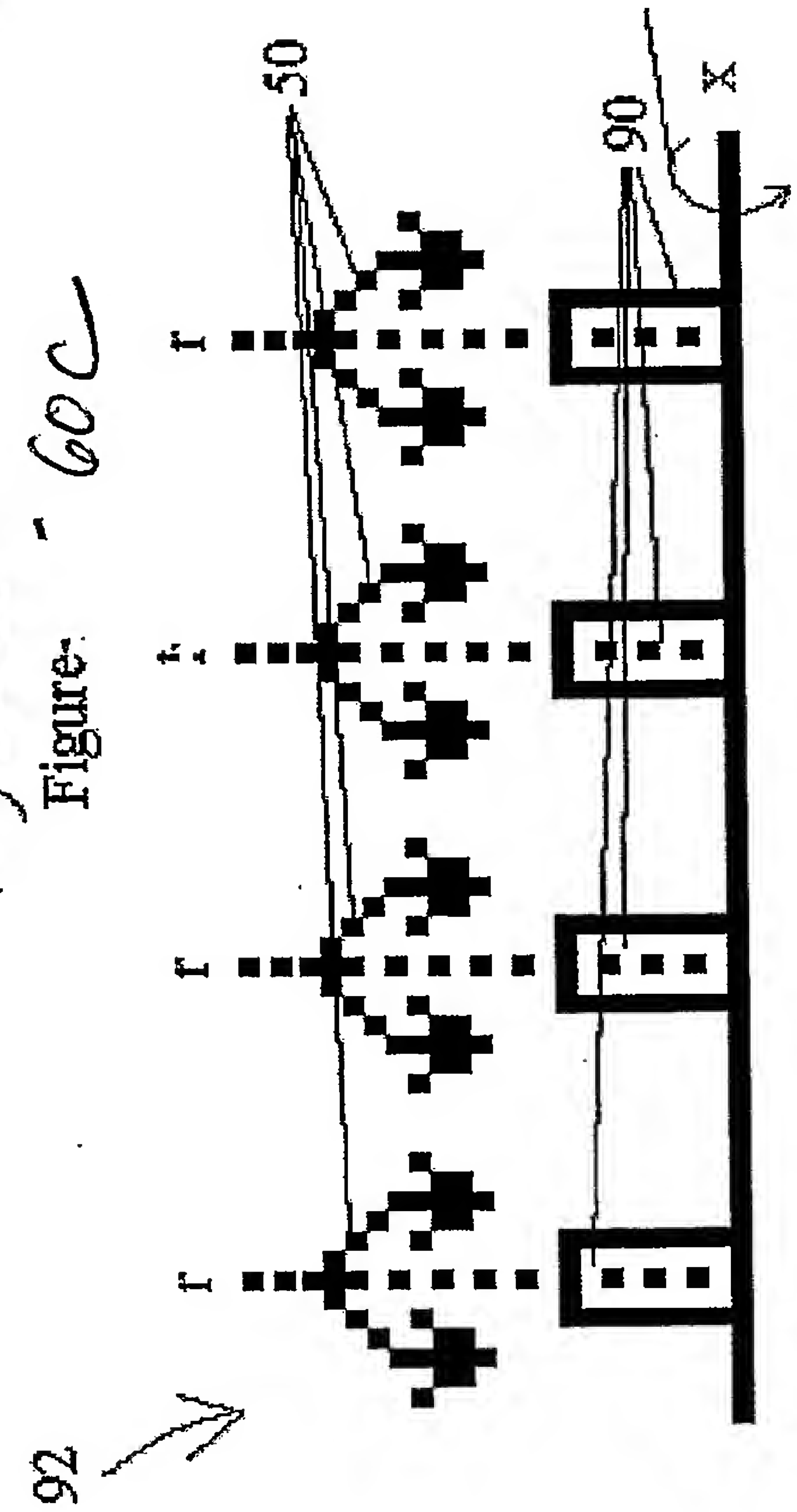


Figure 60A

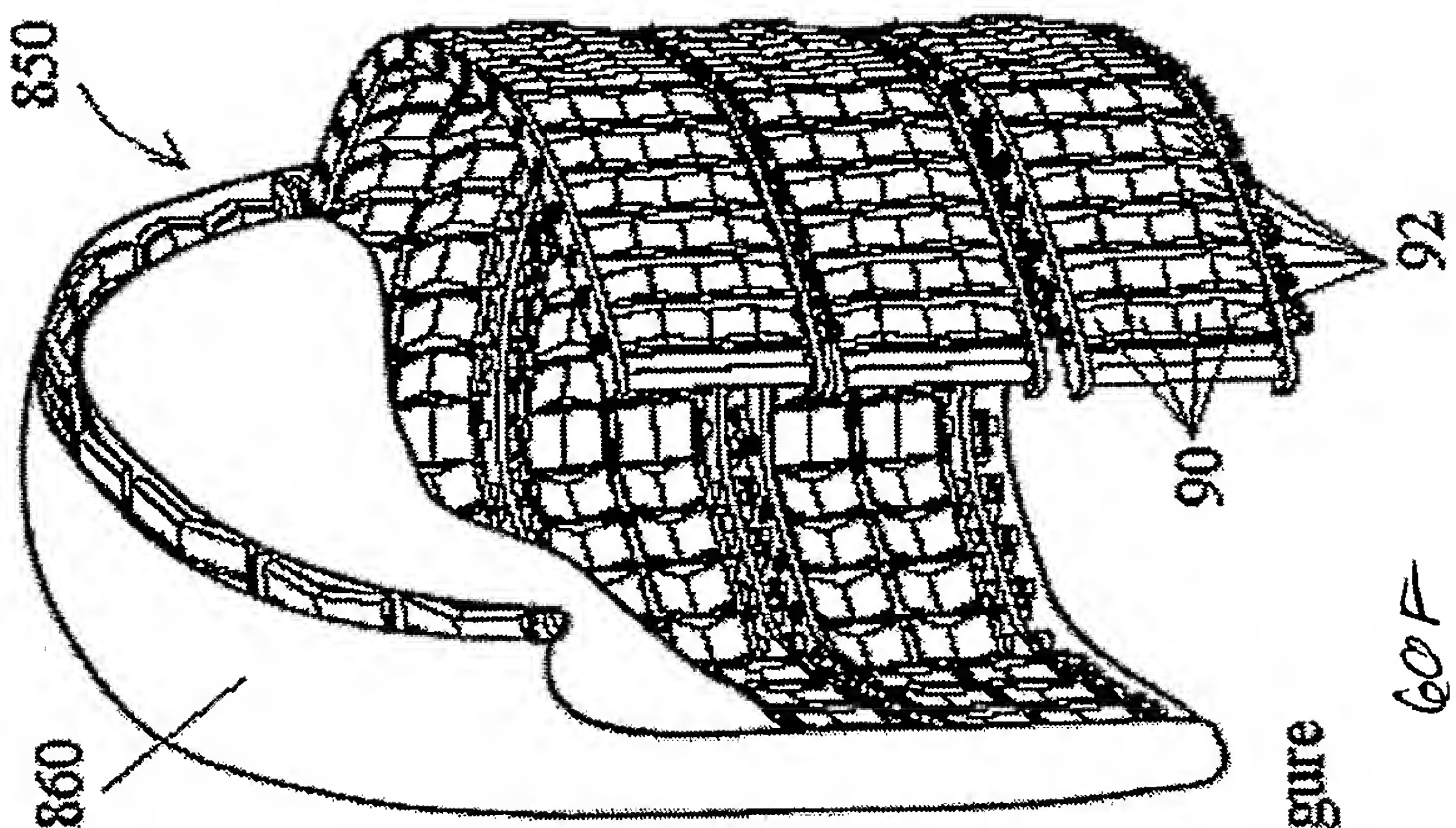


Figure 60F

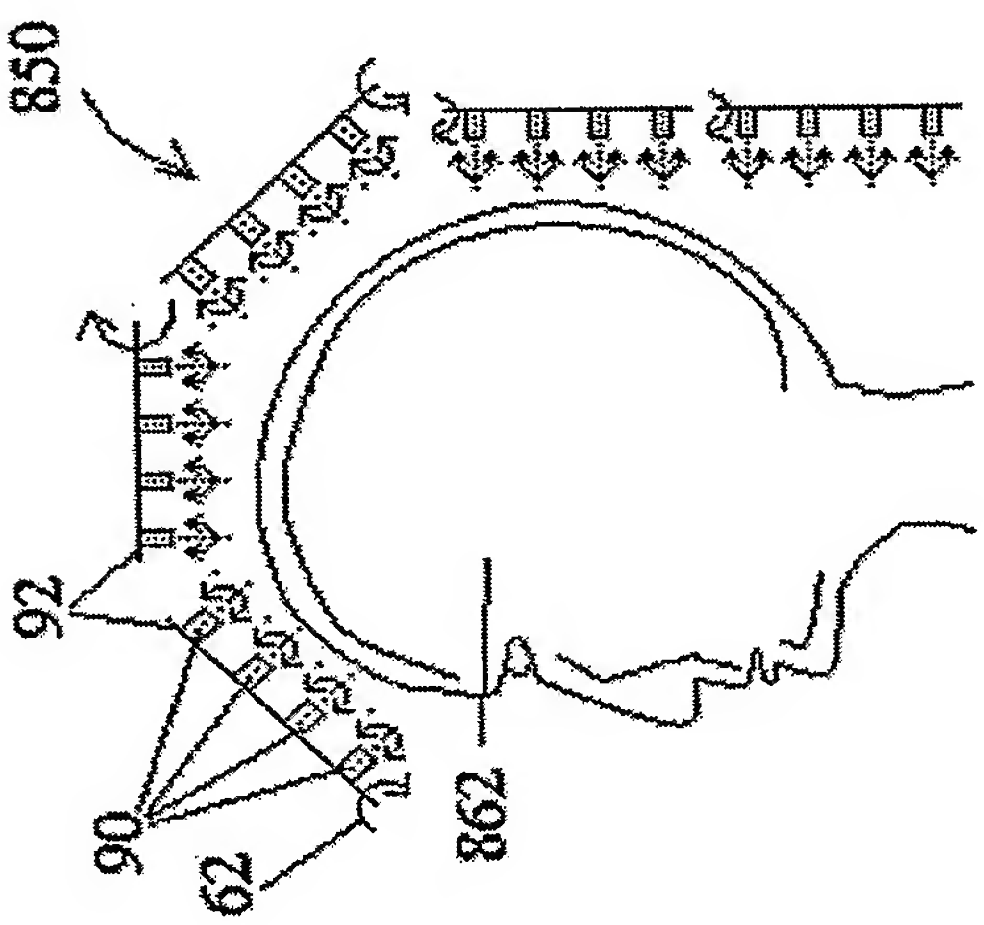


Figure 60E

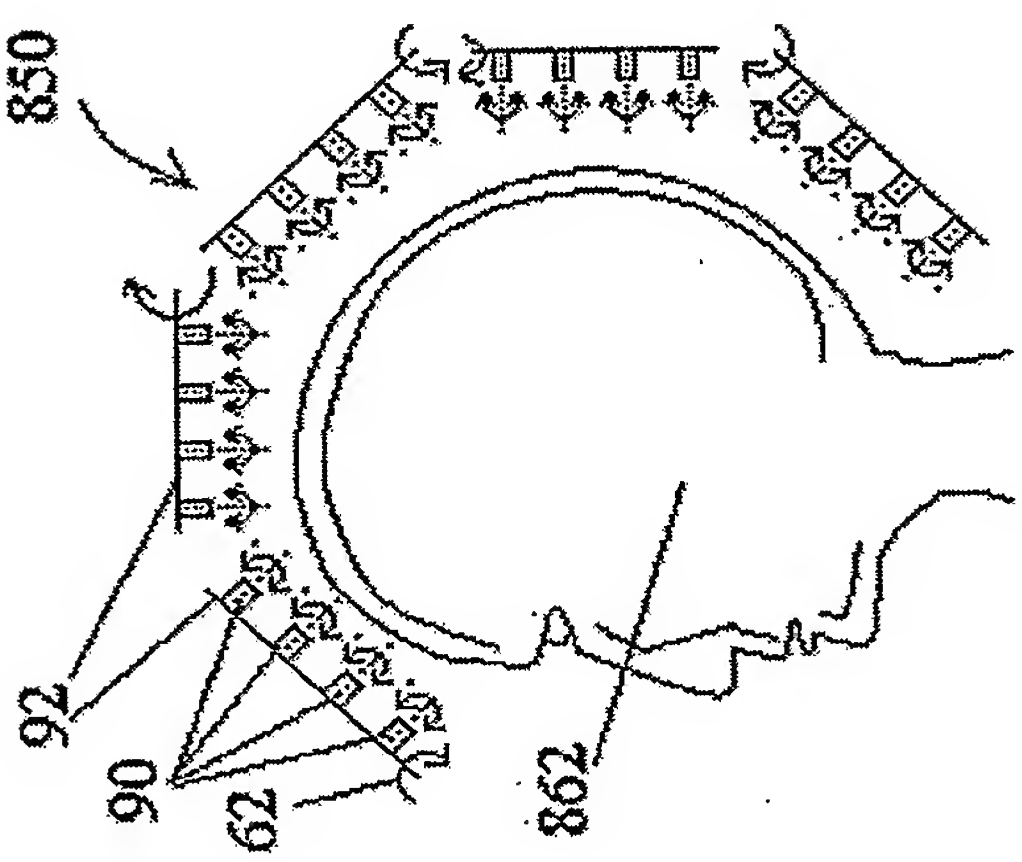


Figure 60D

Figure 60K

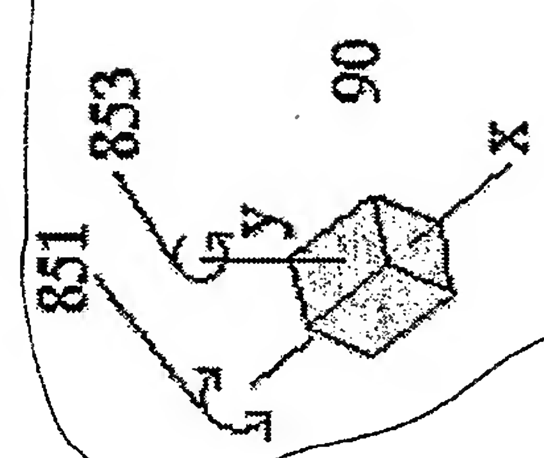


Figure 60J

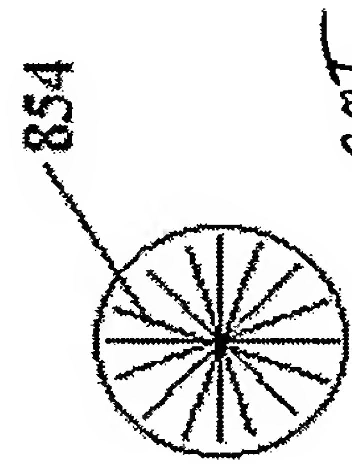


Figure 60I

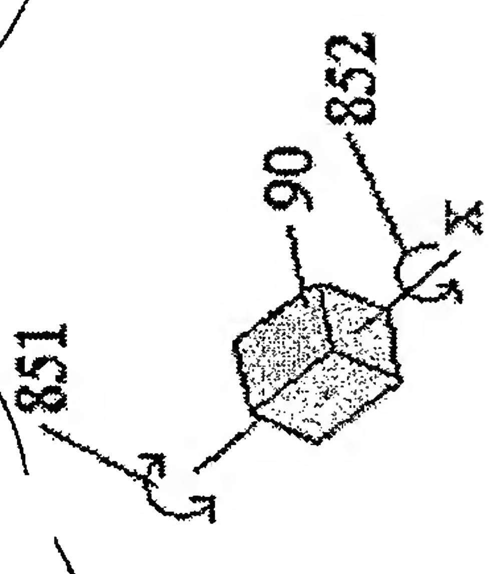


Figure 60H

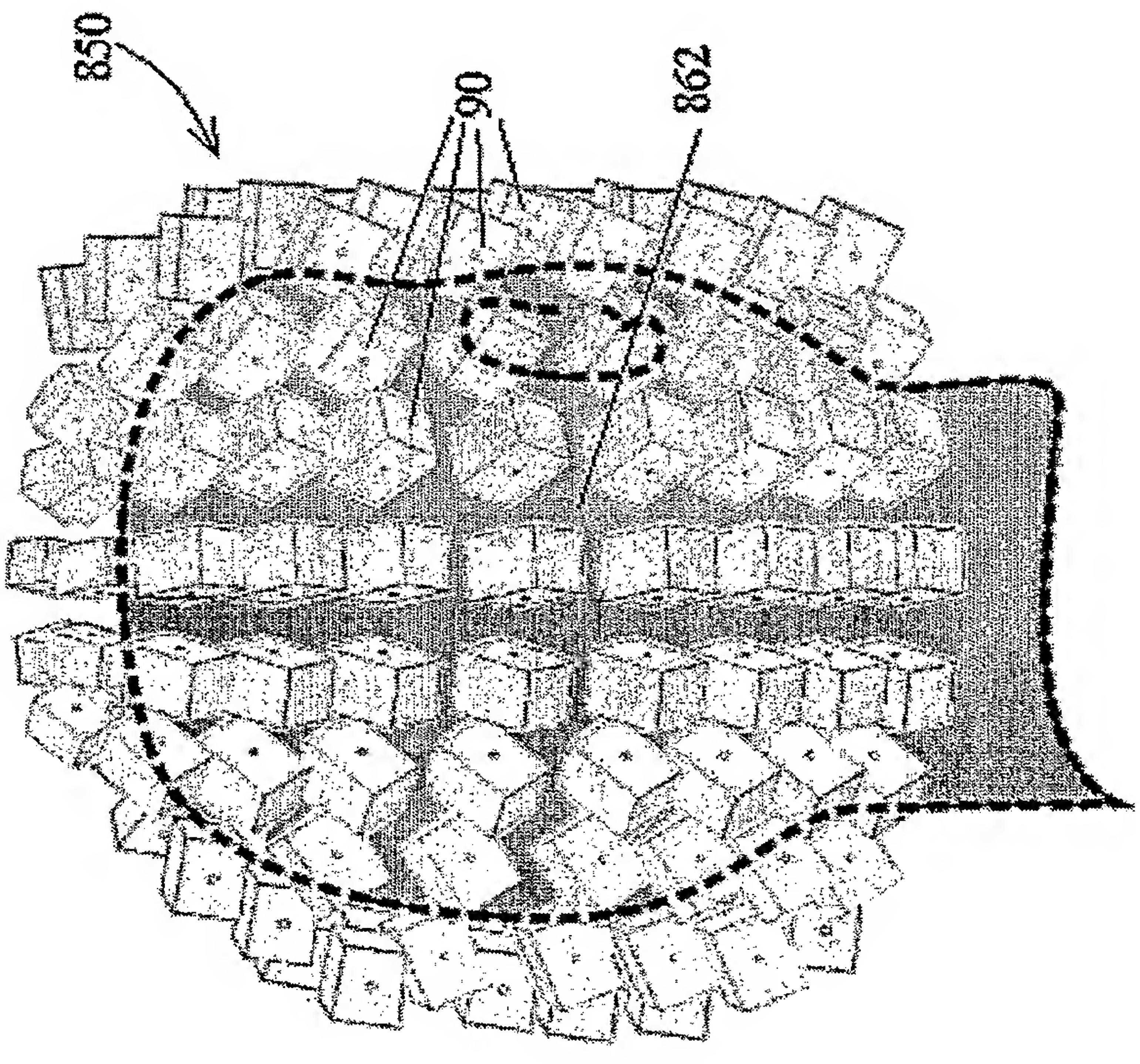


Figure 60G

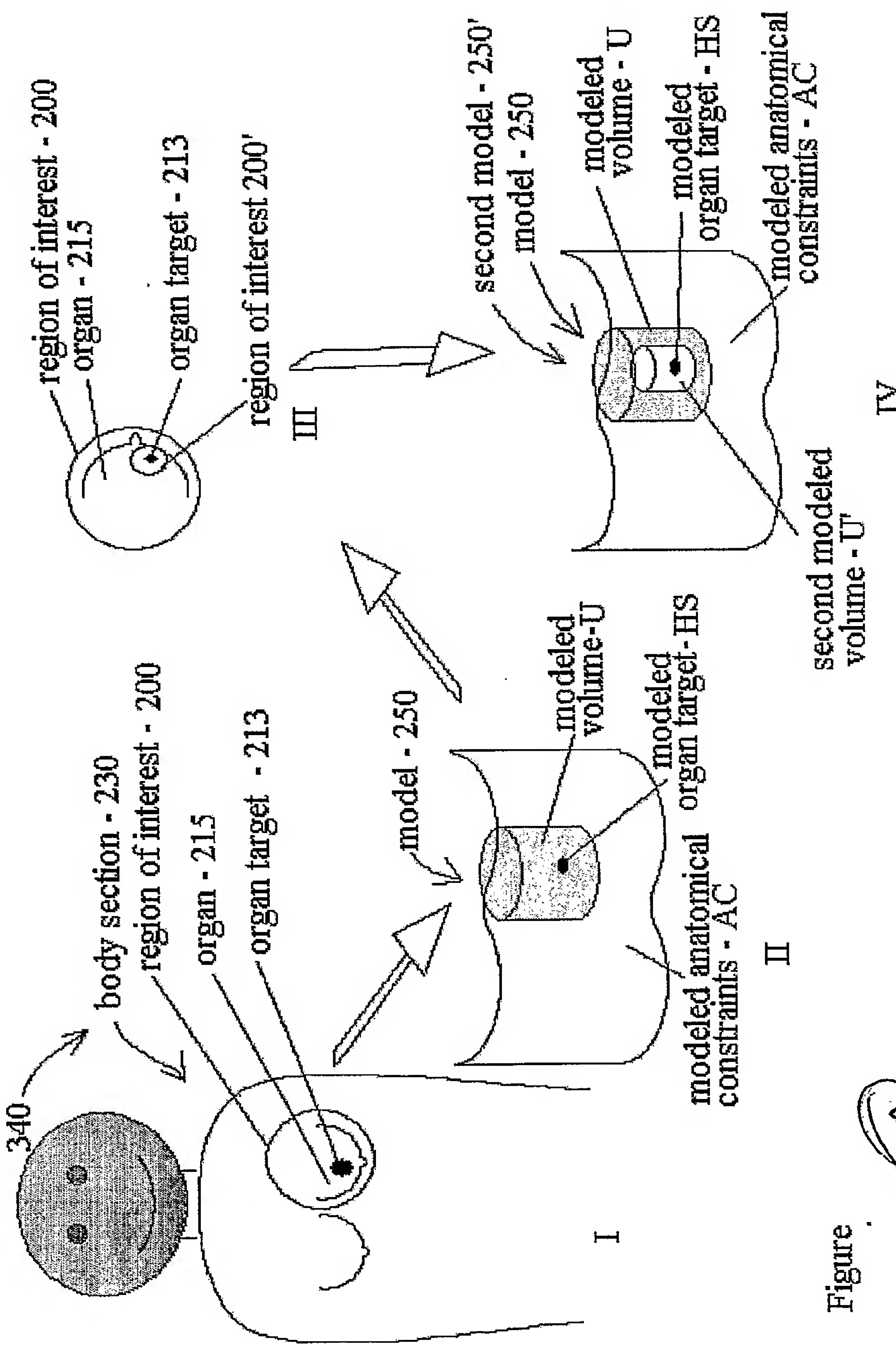

340
body section - 230
region of interest - 200
organ - 215
organ target - 213
I
model - 250
modeled volume-U
modeled organ target-HS
modeled anatomical constraints - AC
II
region of interest - 200
organ - 215
organ target - 213
region of interest 200'
III
second model - 250'
model - 250
modeled volume - U
modeled organ target - HS
modeled anatomical constraints - AC
second modeled volume - U'
IV

Figure 61A

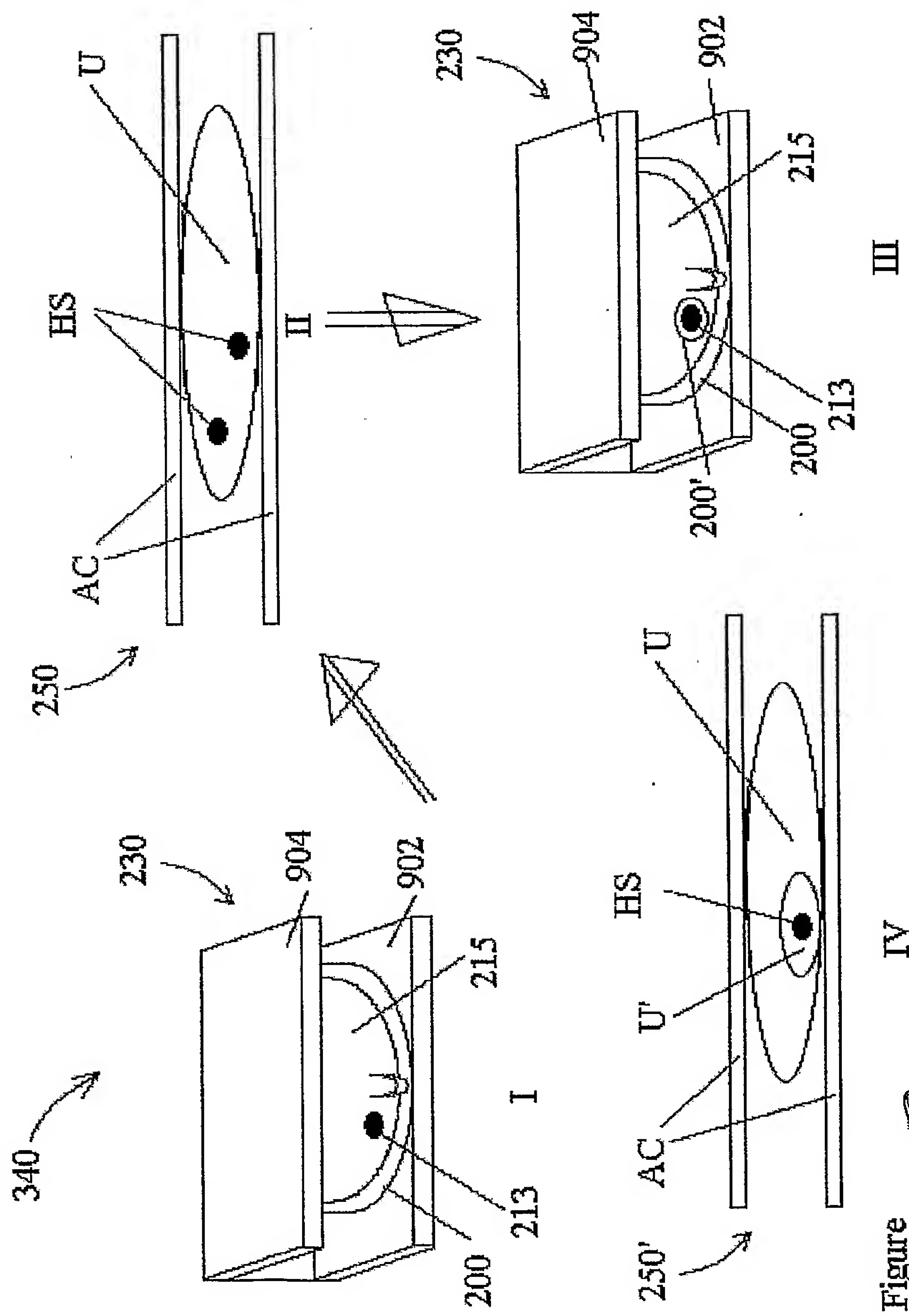

340
230
904
902
215
U
213
200
I
250
AC
HS
U
II
230
904
902
215
U
213
200
200'
III
250'
AC
U'
HS
U
IV

Figure 61B

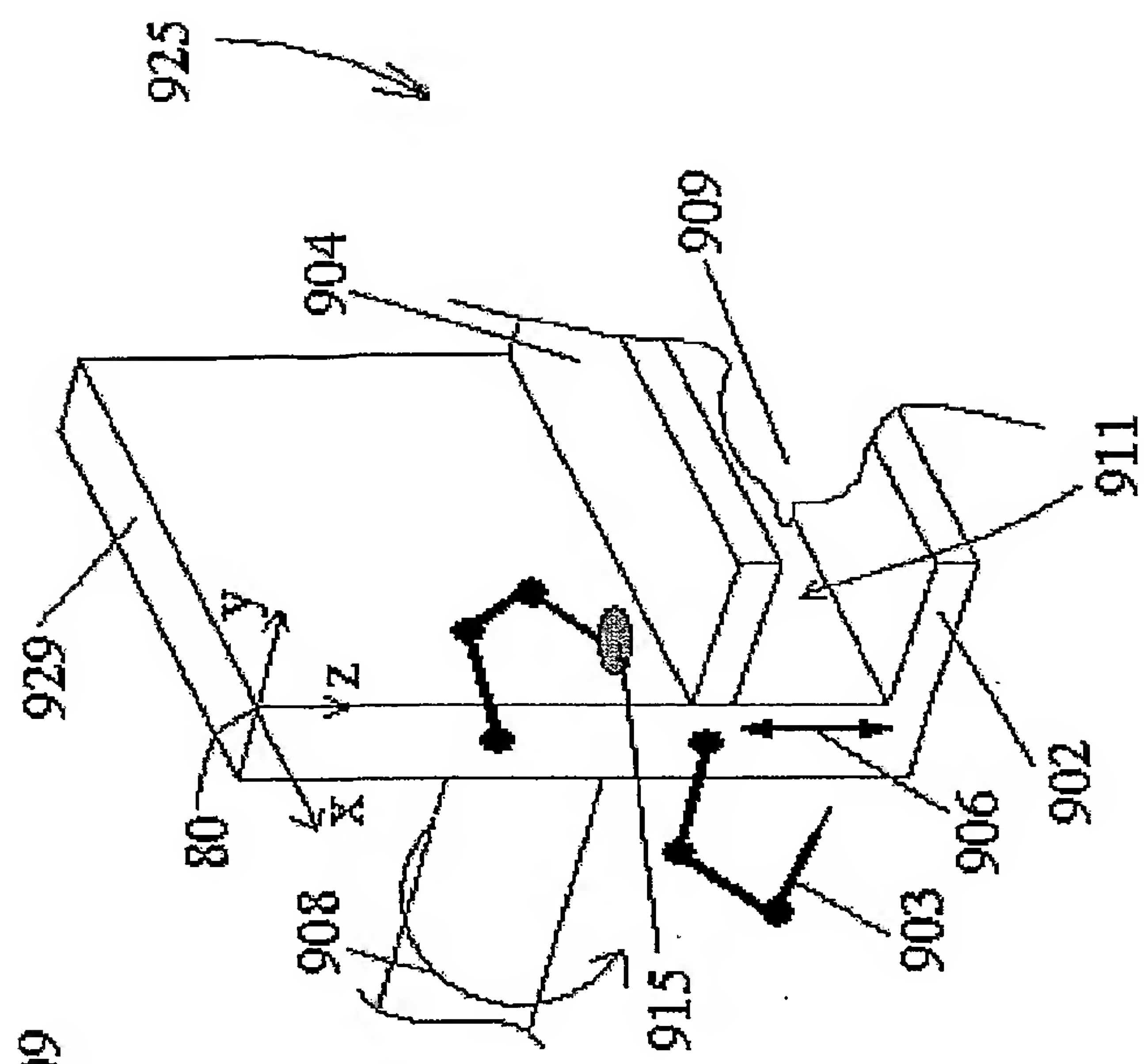


Figure 62C

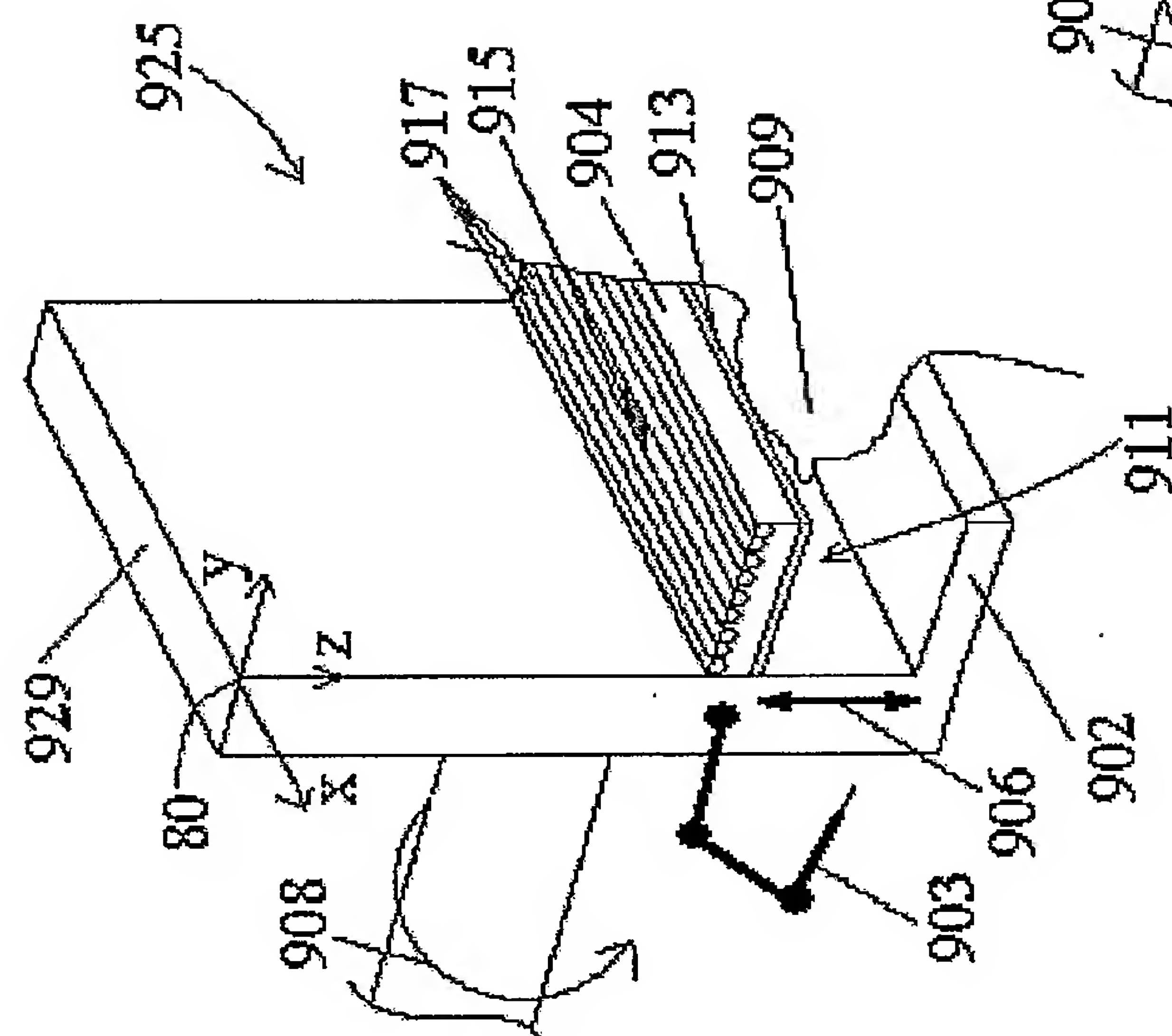


Figure 62B

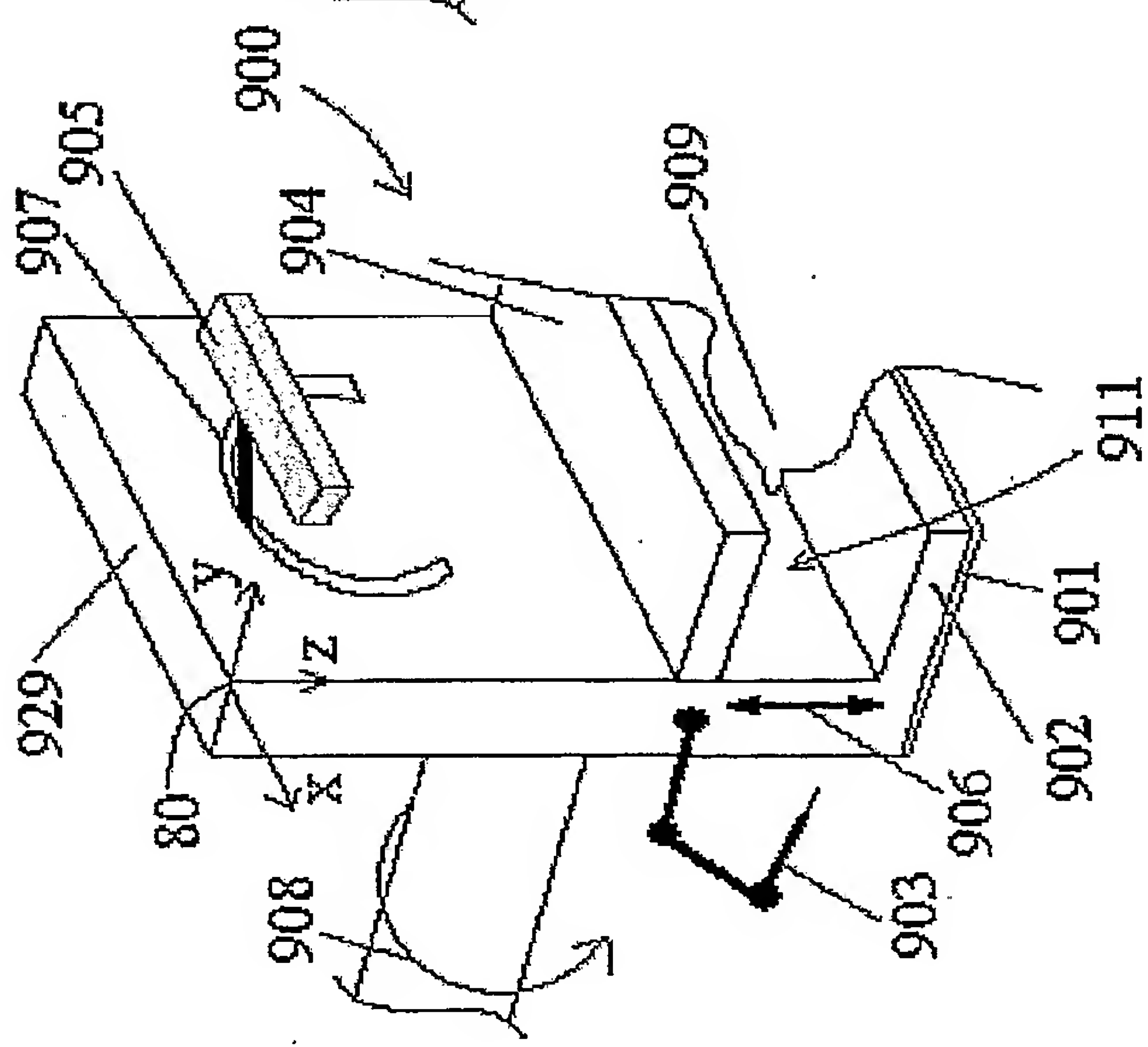


Figure 62A

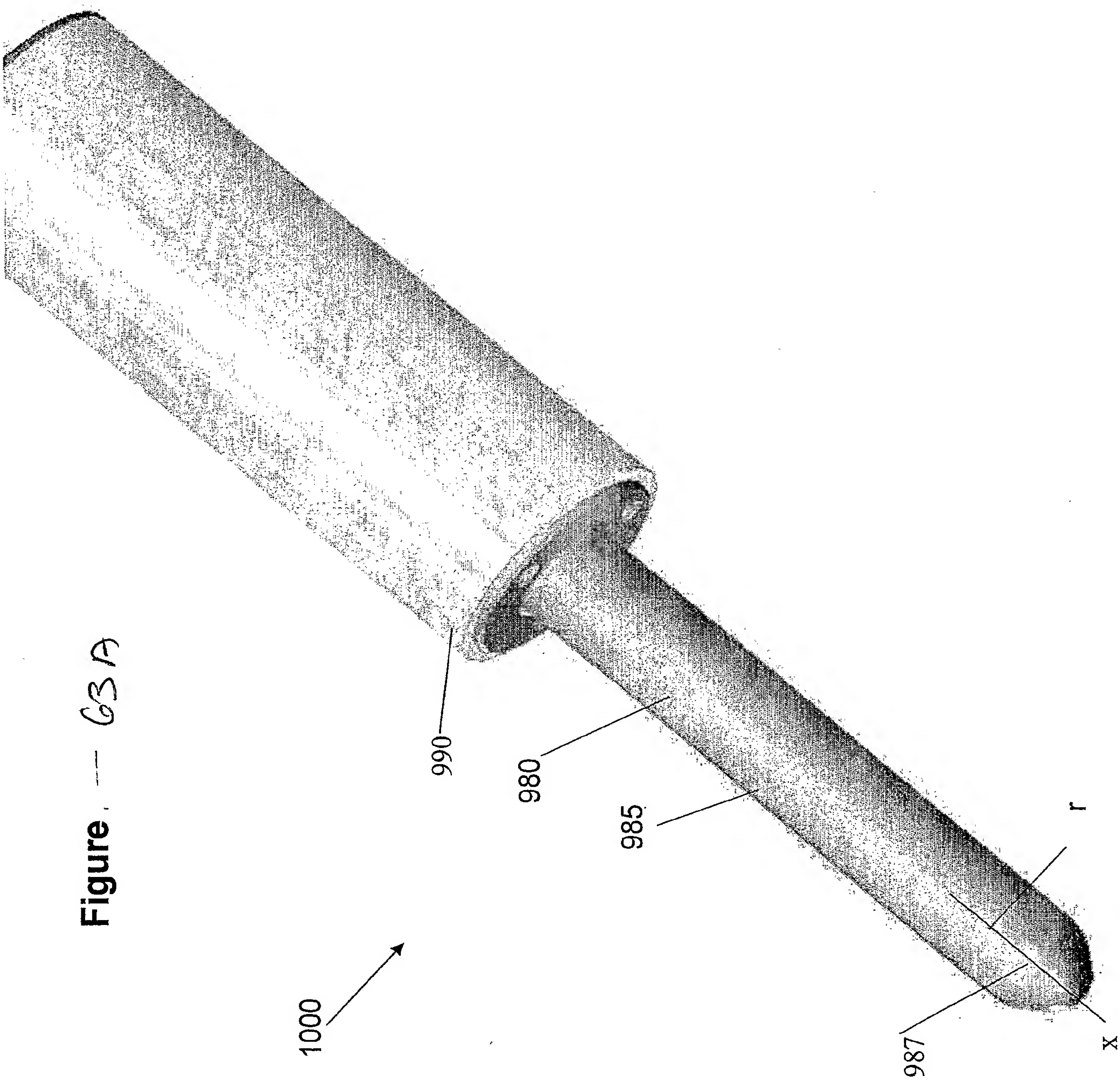


Figure — 63A

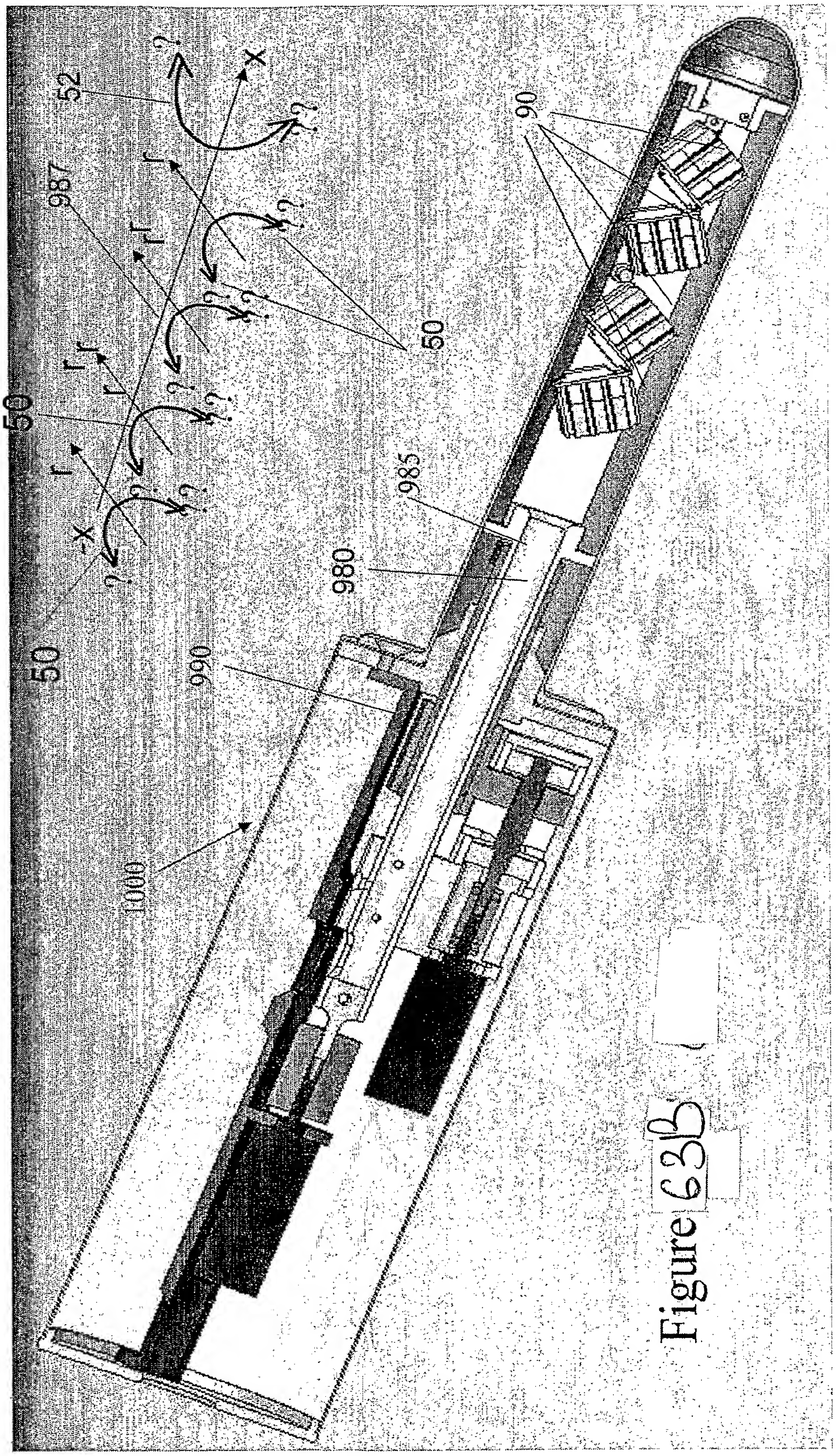


Figure 63B

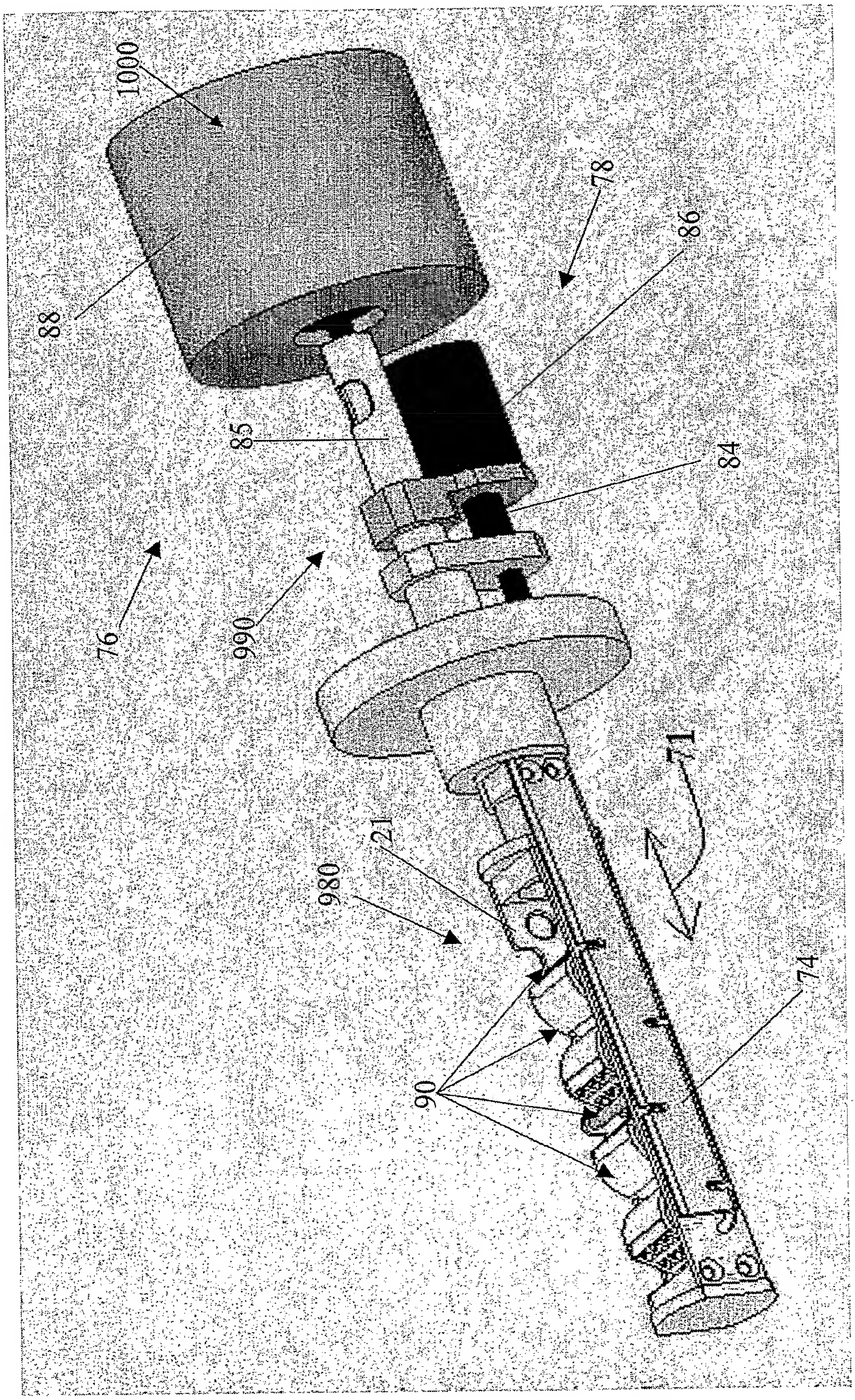


Figure 63C

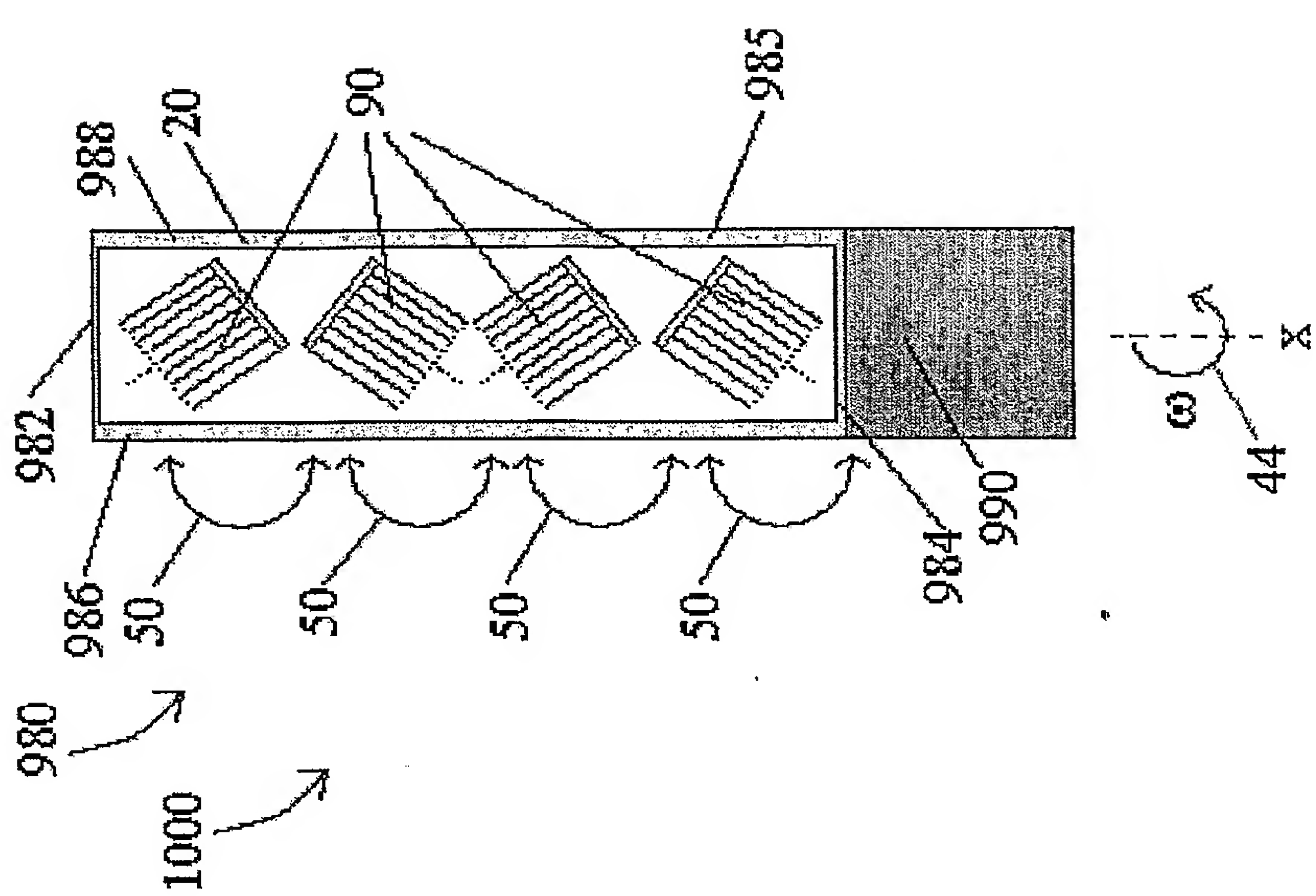


Figure 63E

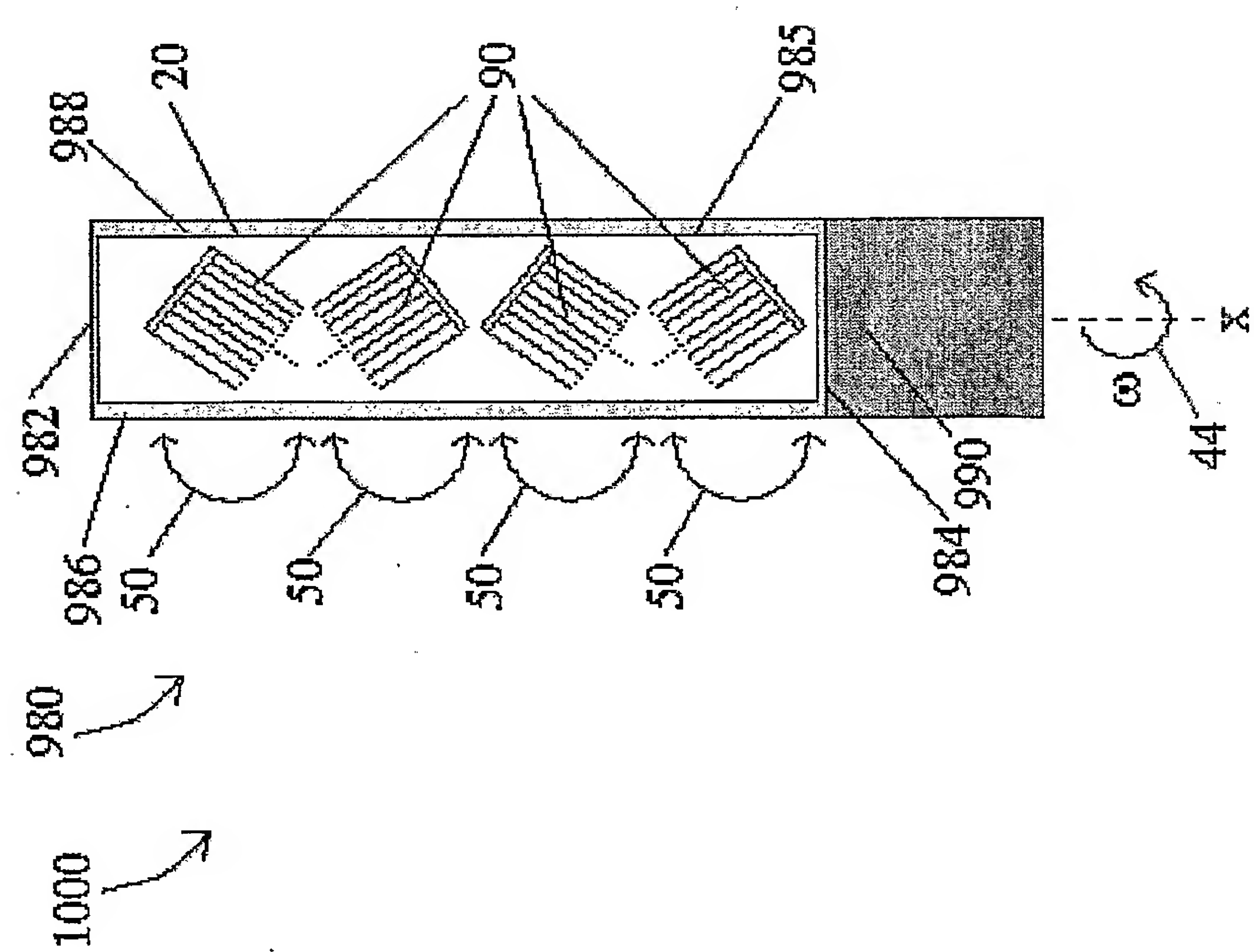


Figure 63D

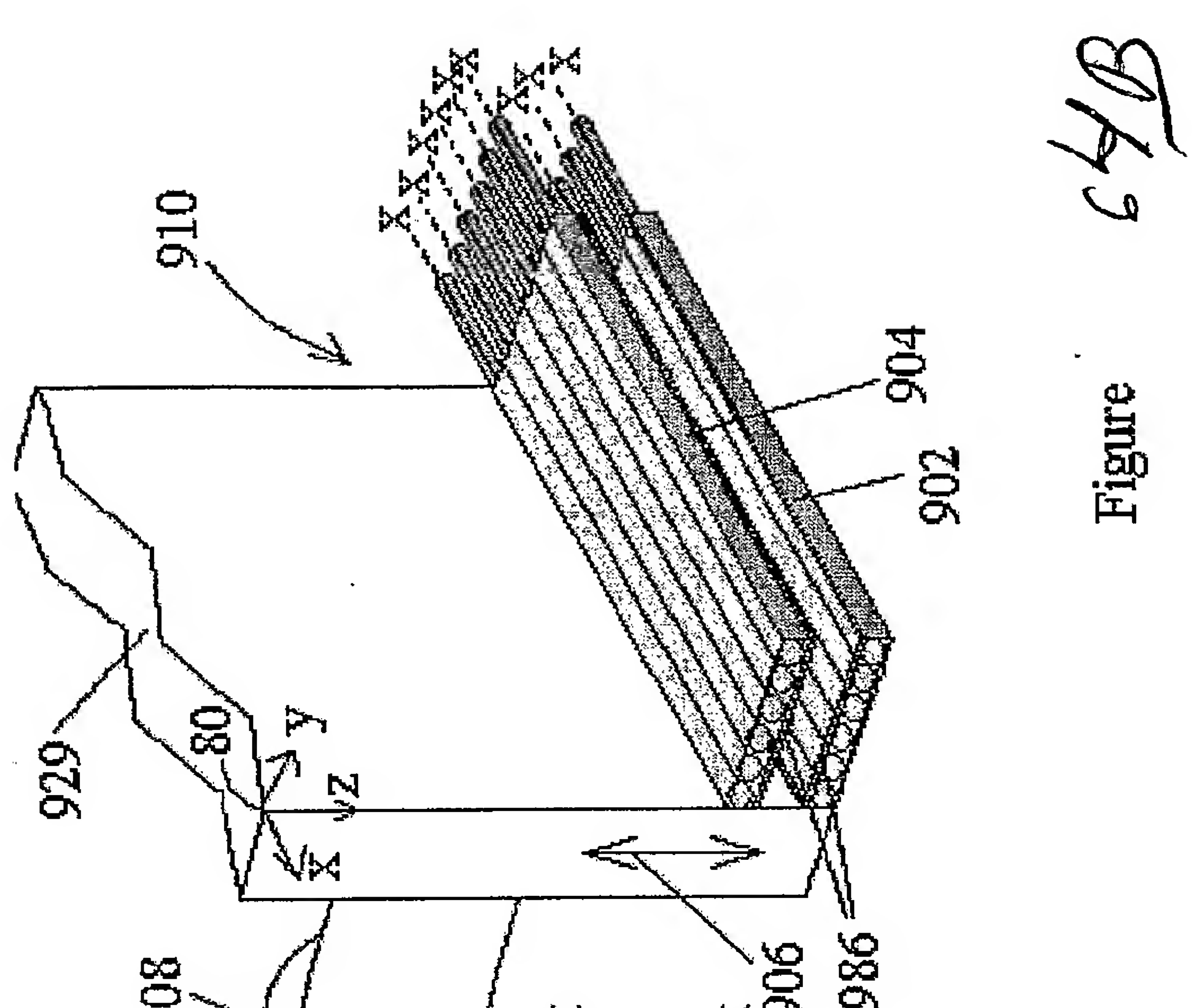


Figure 64B

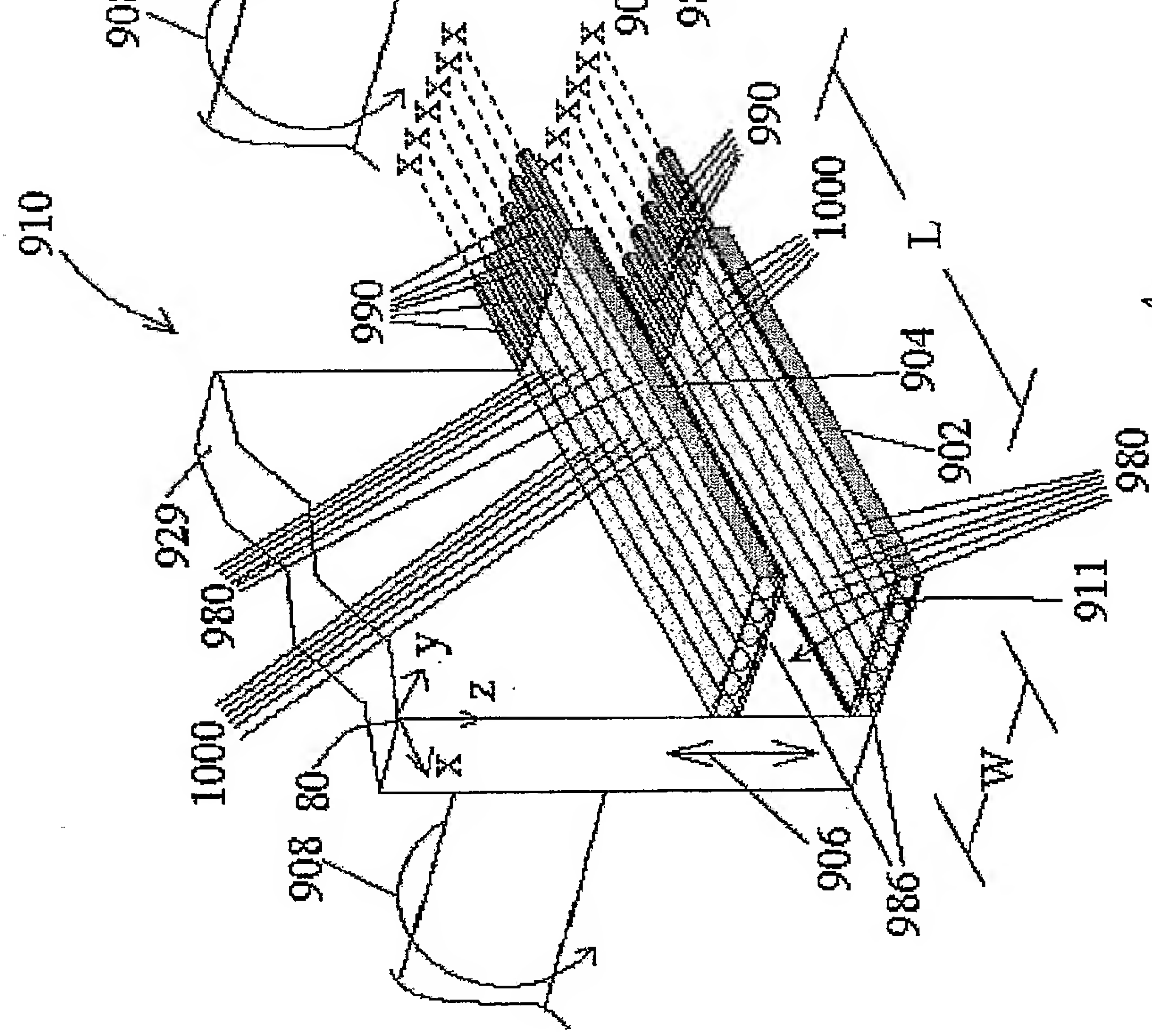


Figure 64A

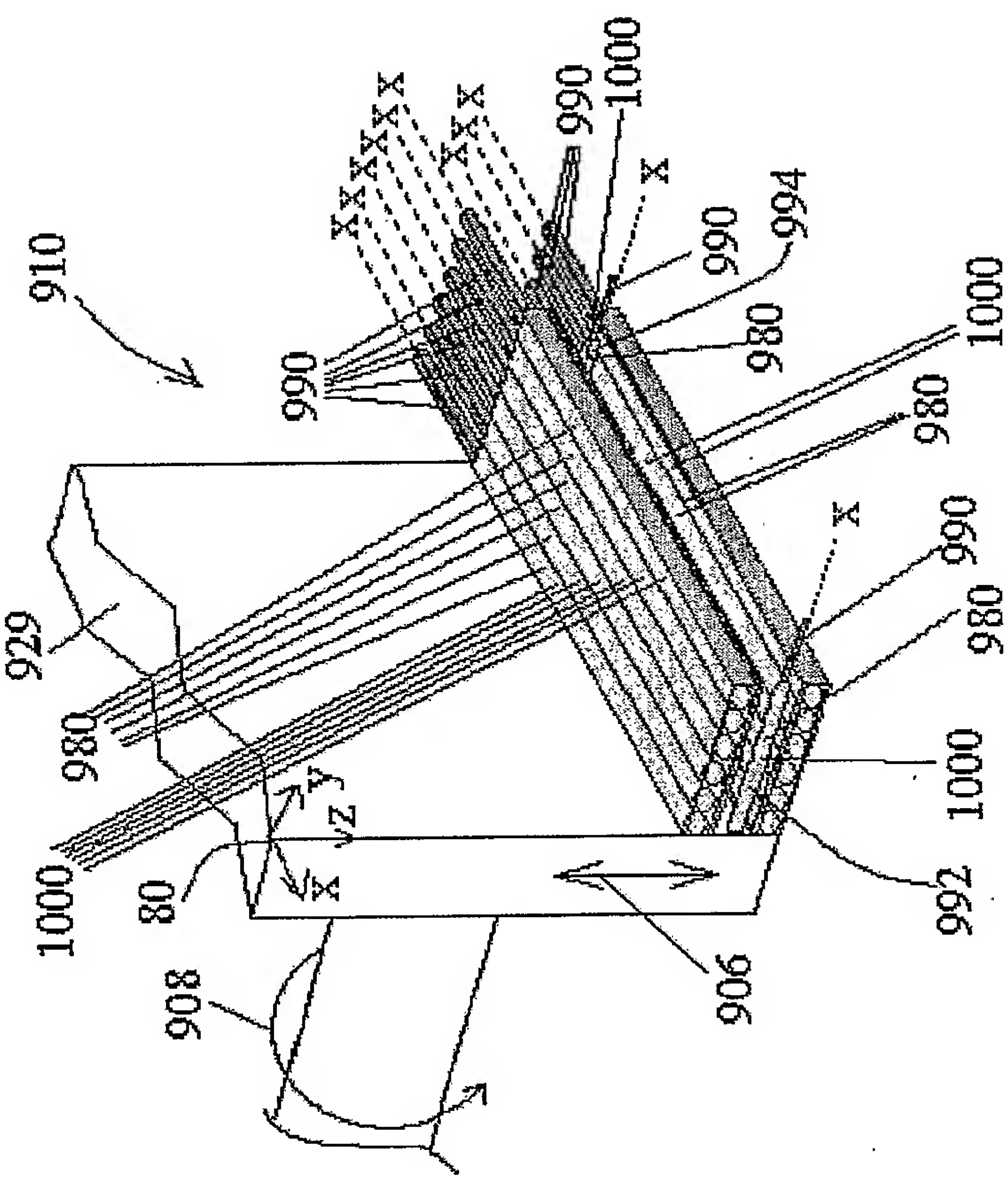


Figure 64C

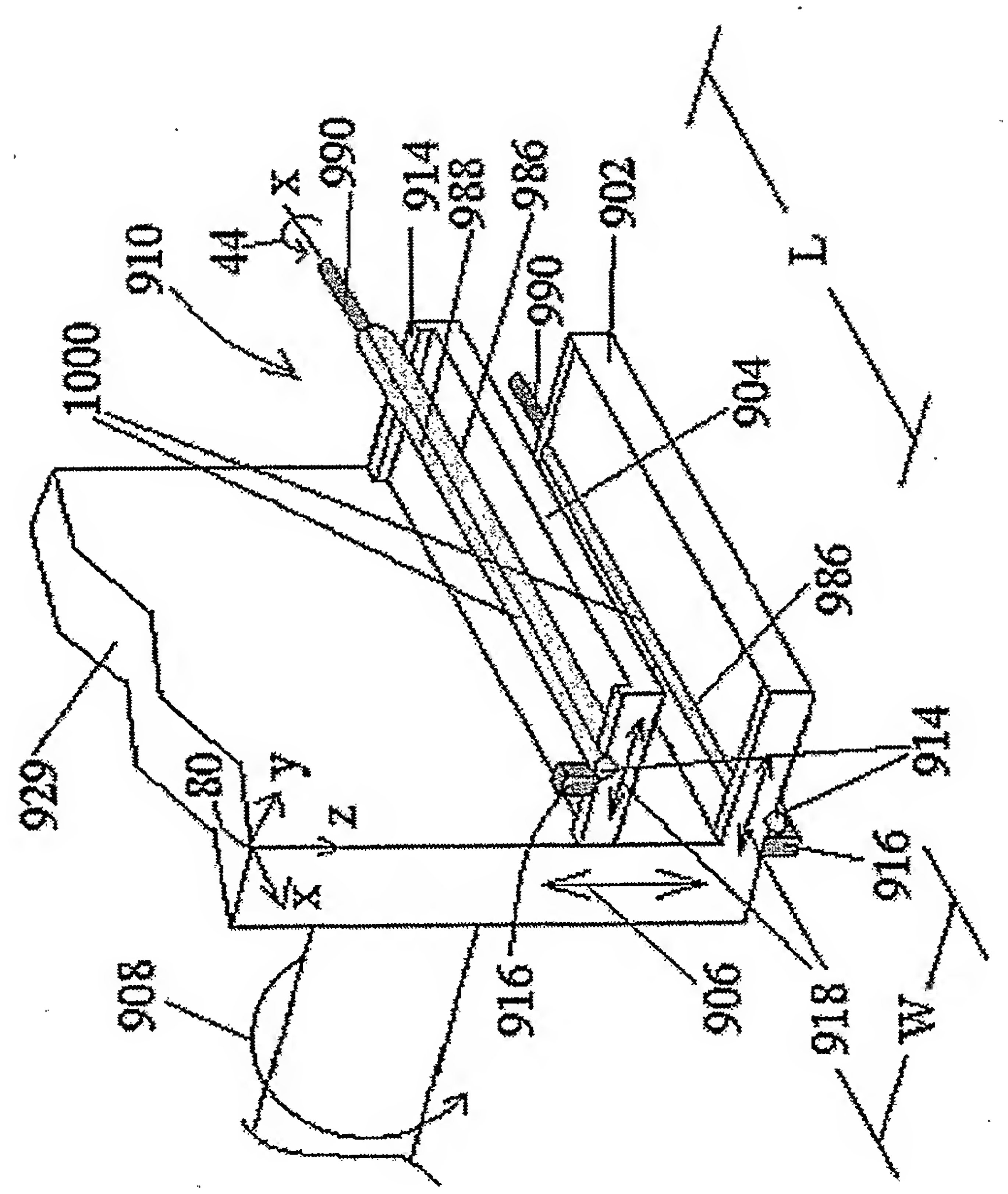


Figure: 64D

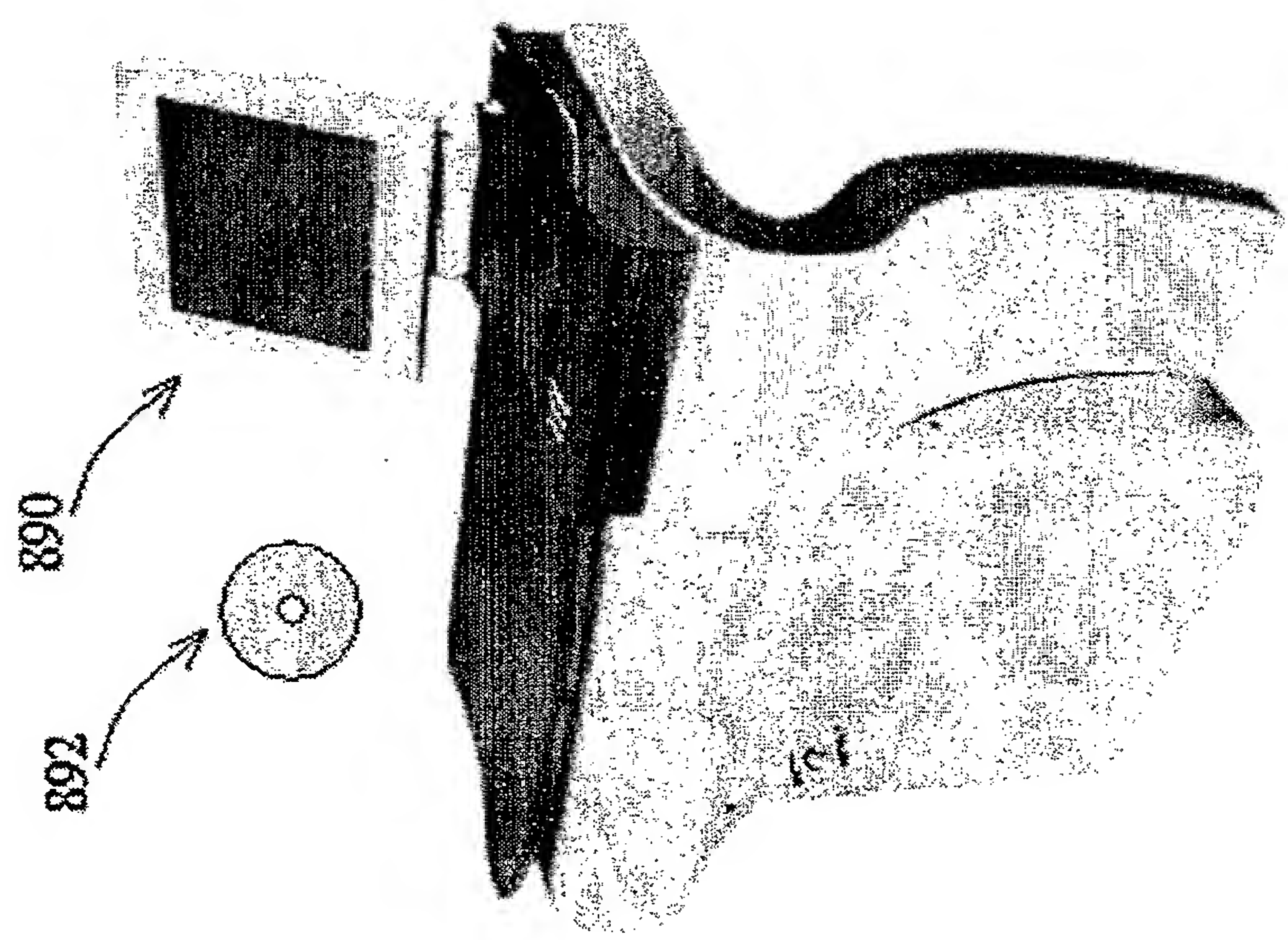


Figure: 64E

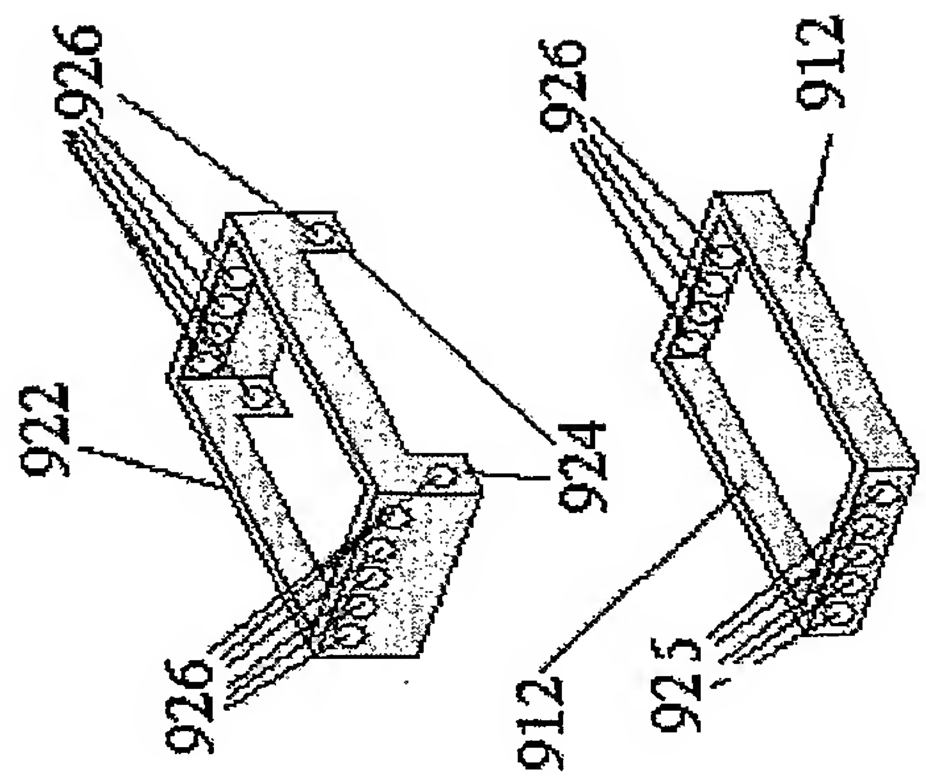


Figure 64I

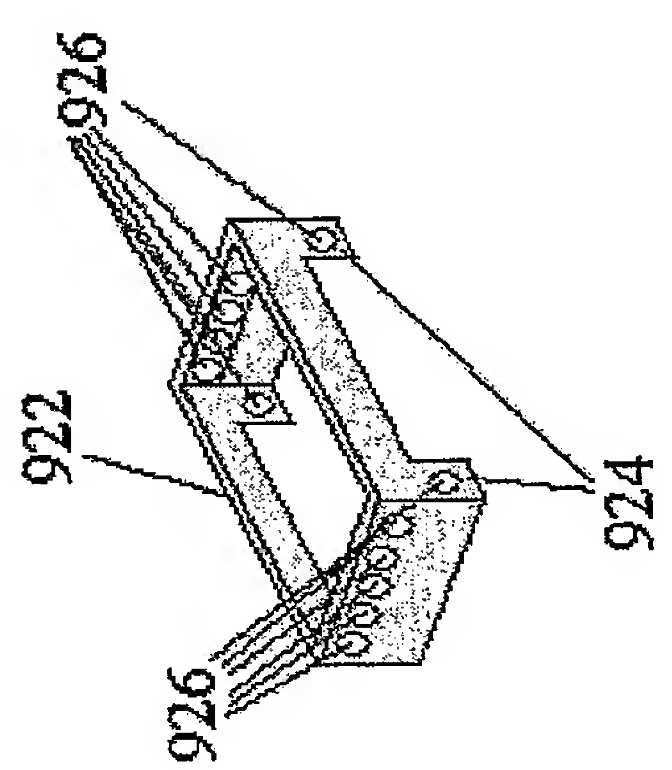


Figure 64H

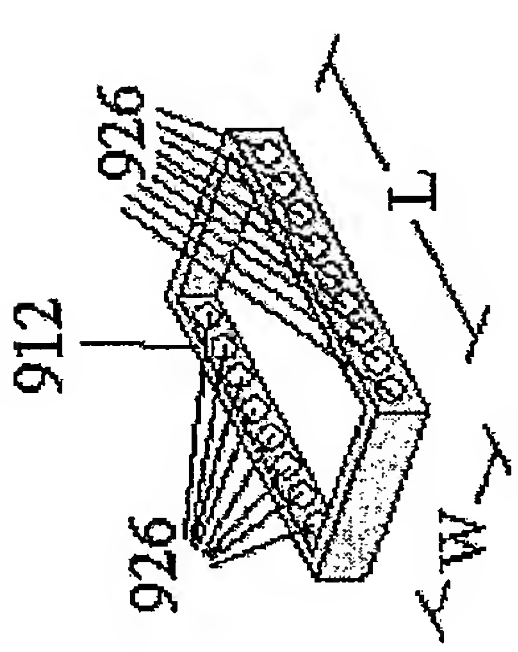


Figure 64G

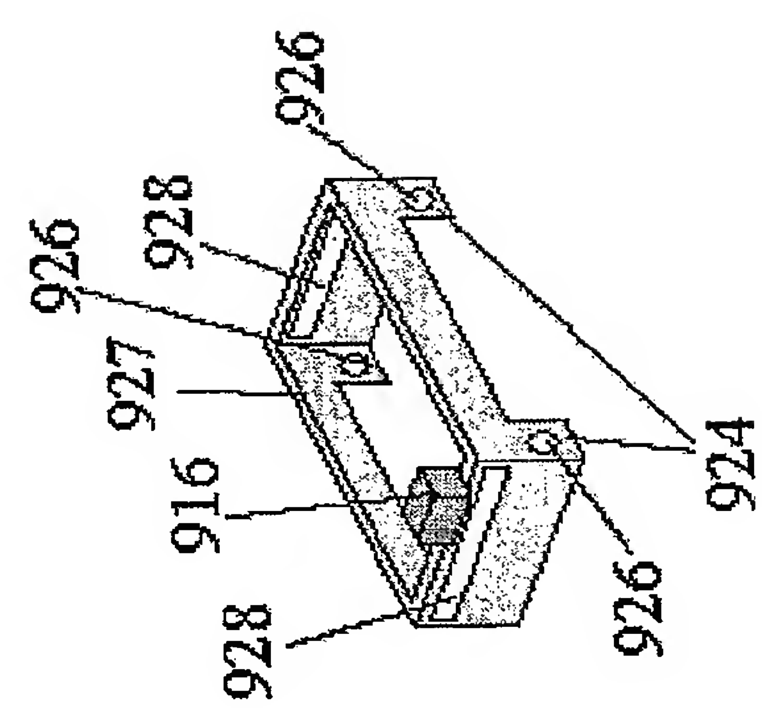


Figure 64K

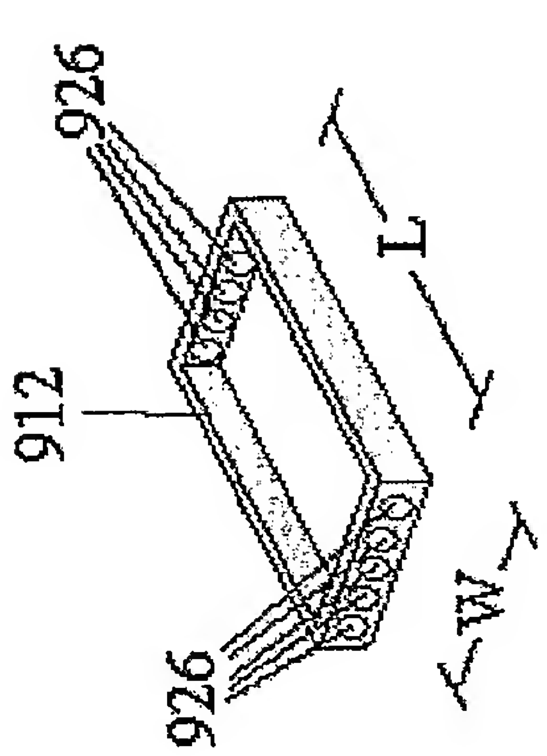


Figure 64F

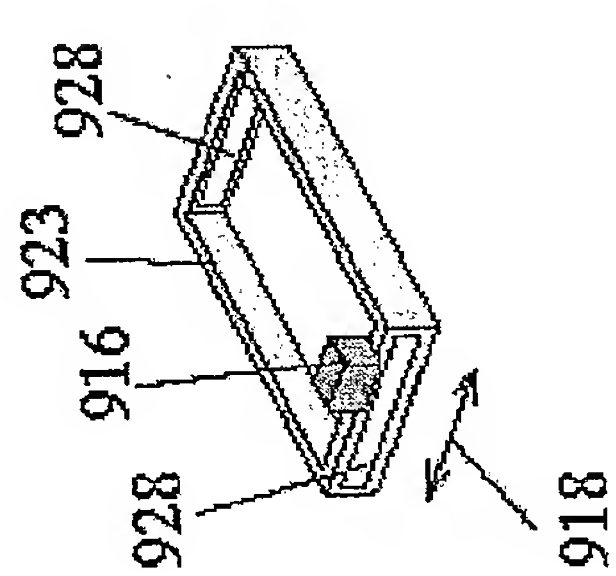


Figure 64J

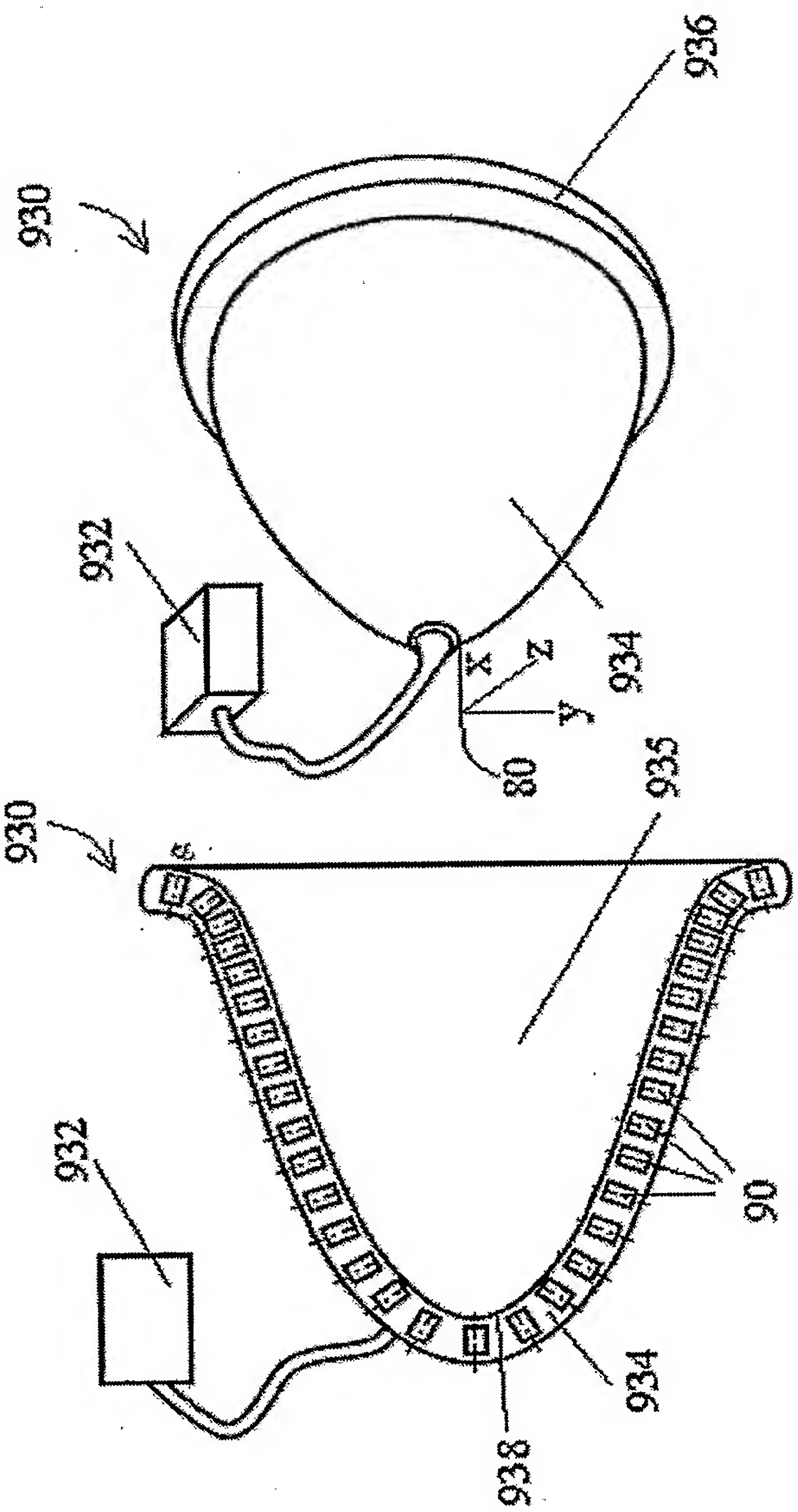


Figure 65A

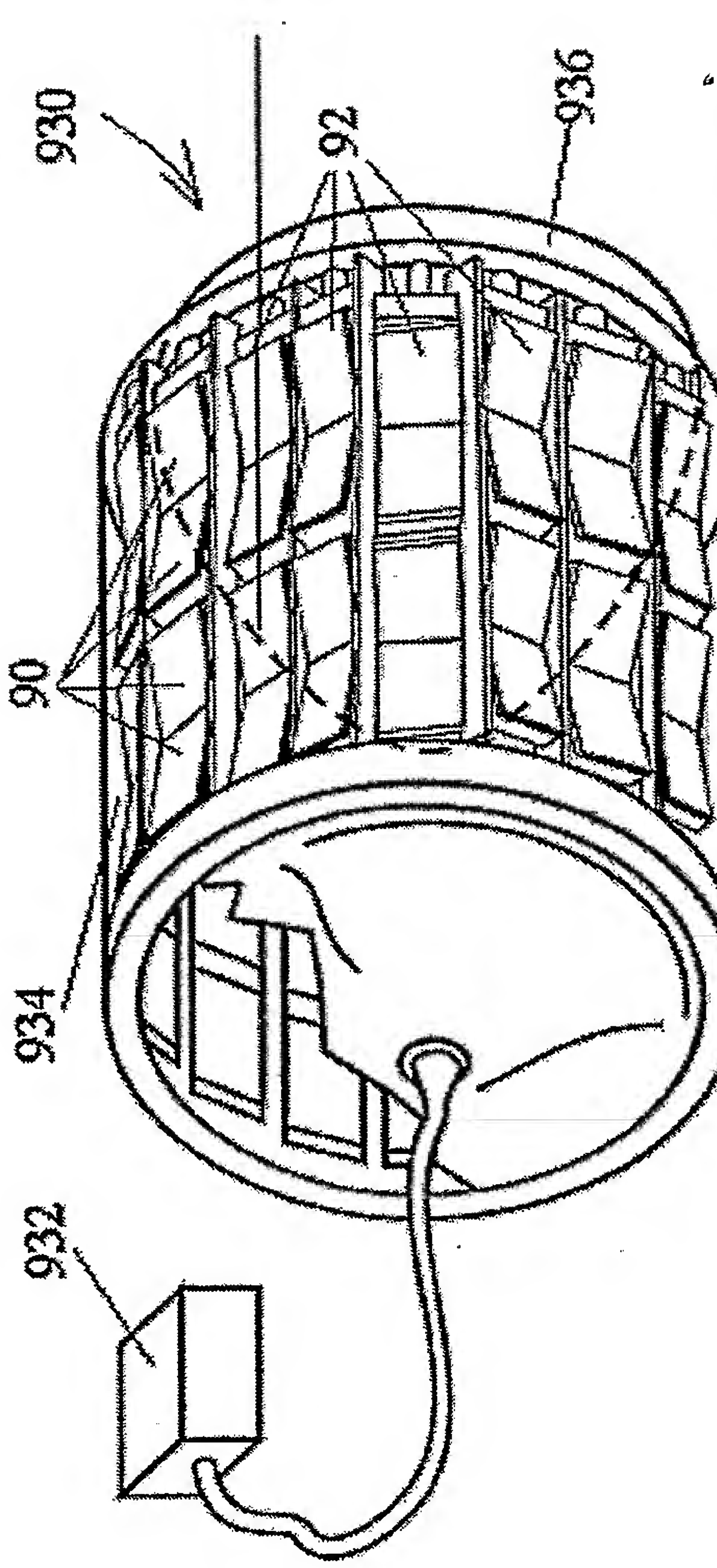


Figure 65B

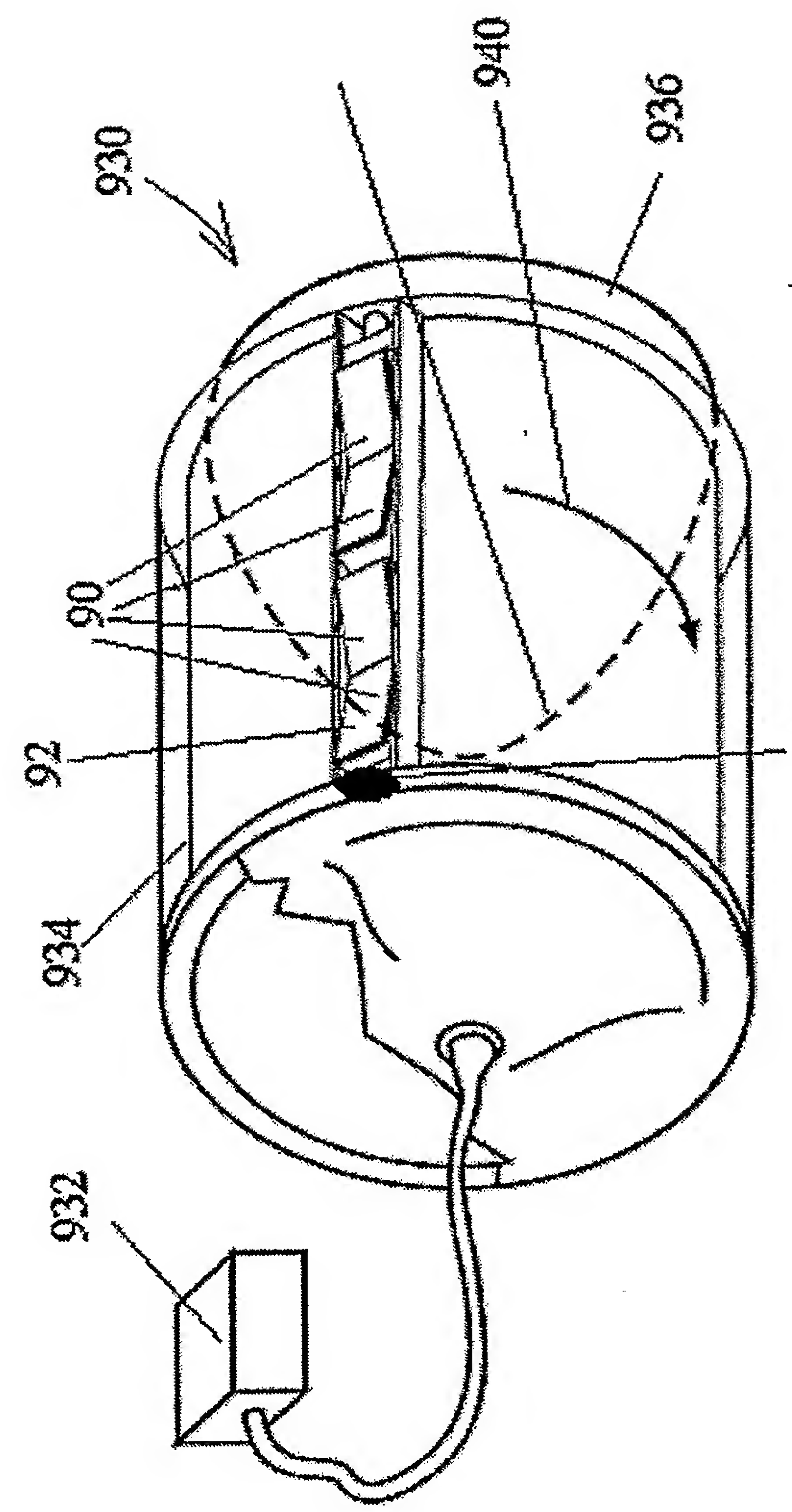


Figure 65C

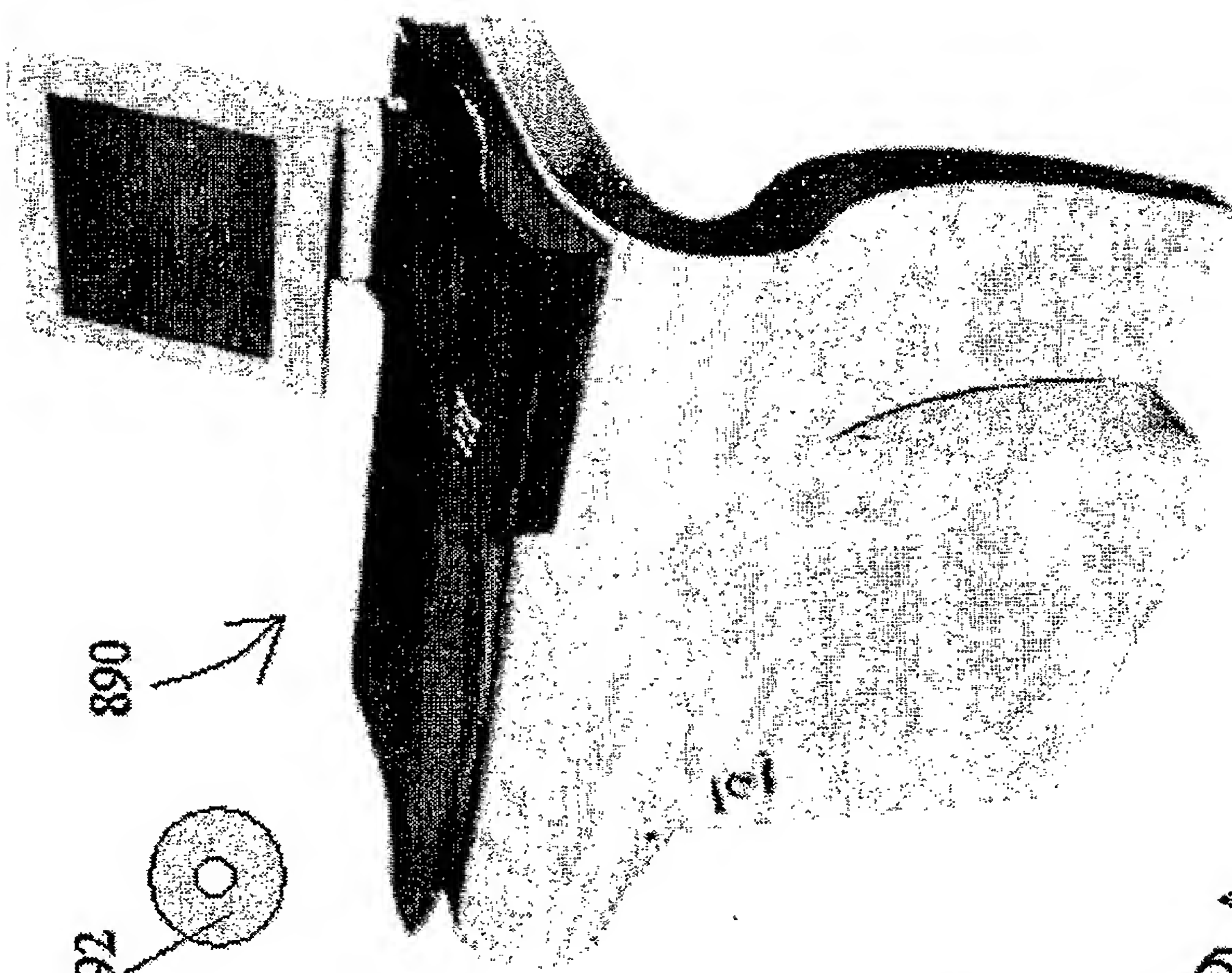


Figure 66C

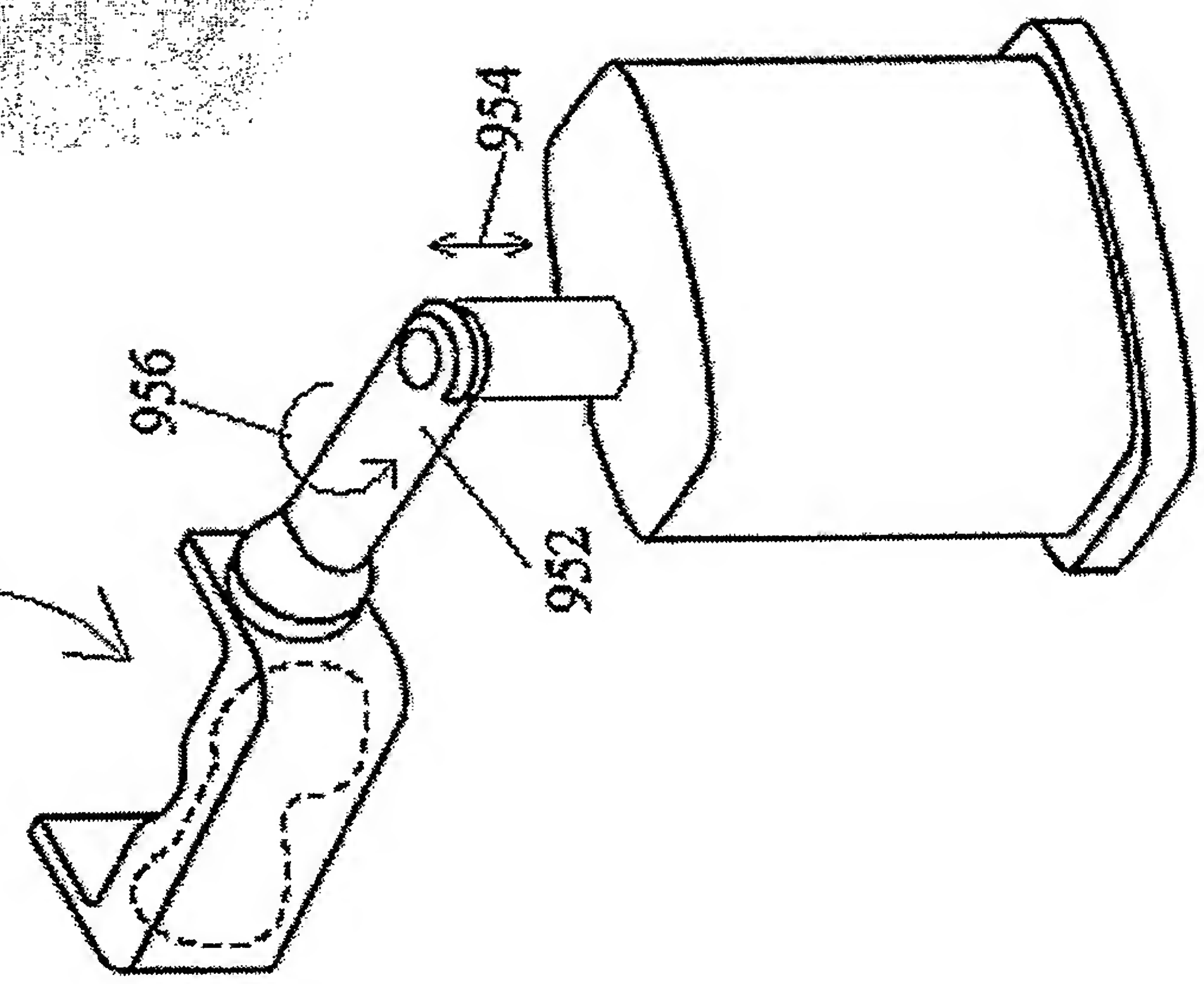


Figure 66A

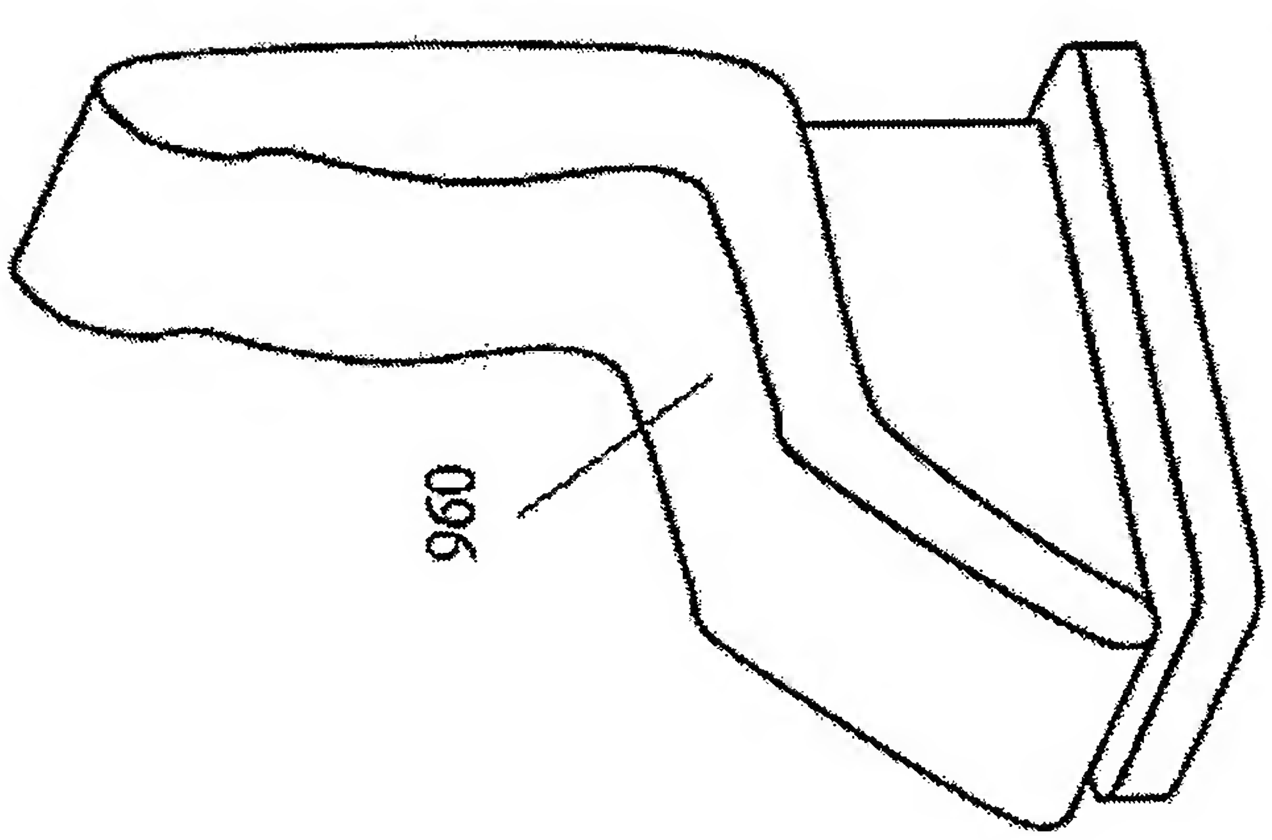


Figure 66B

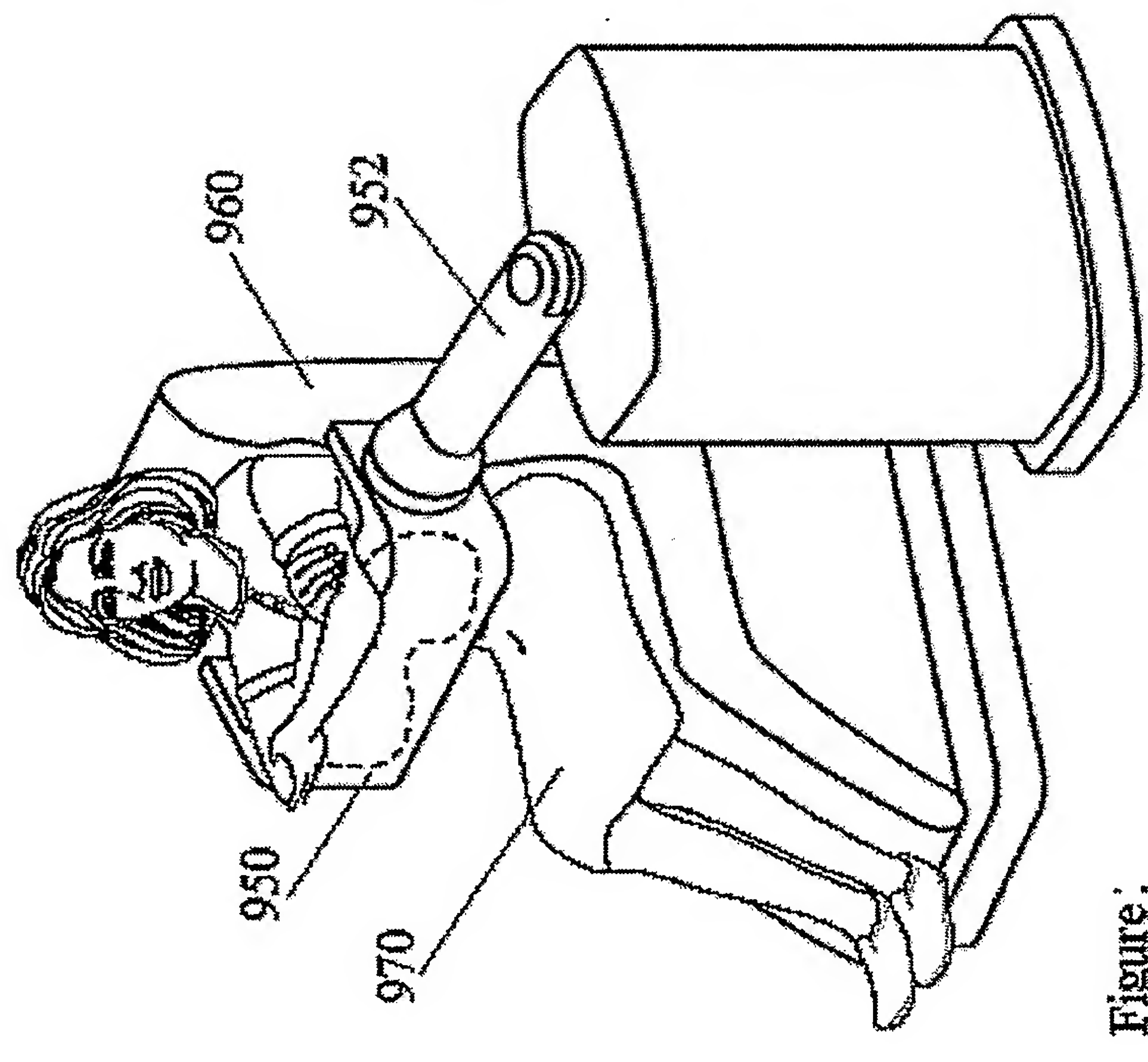


Figure: 66D

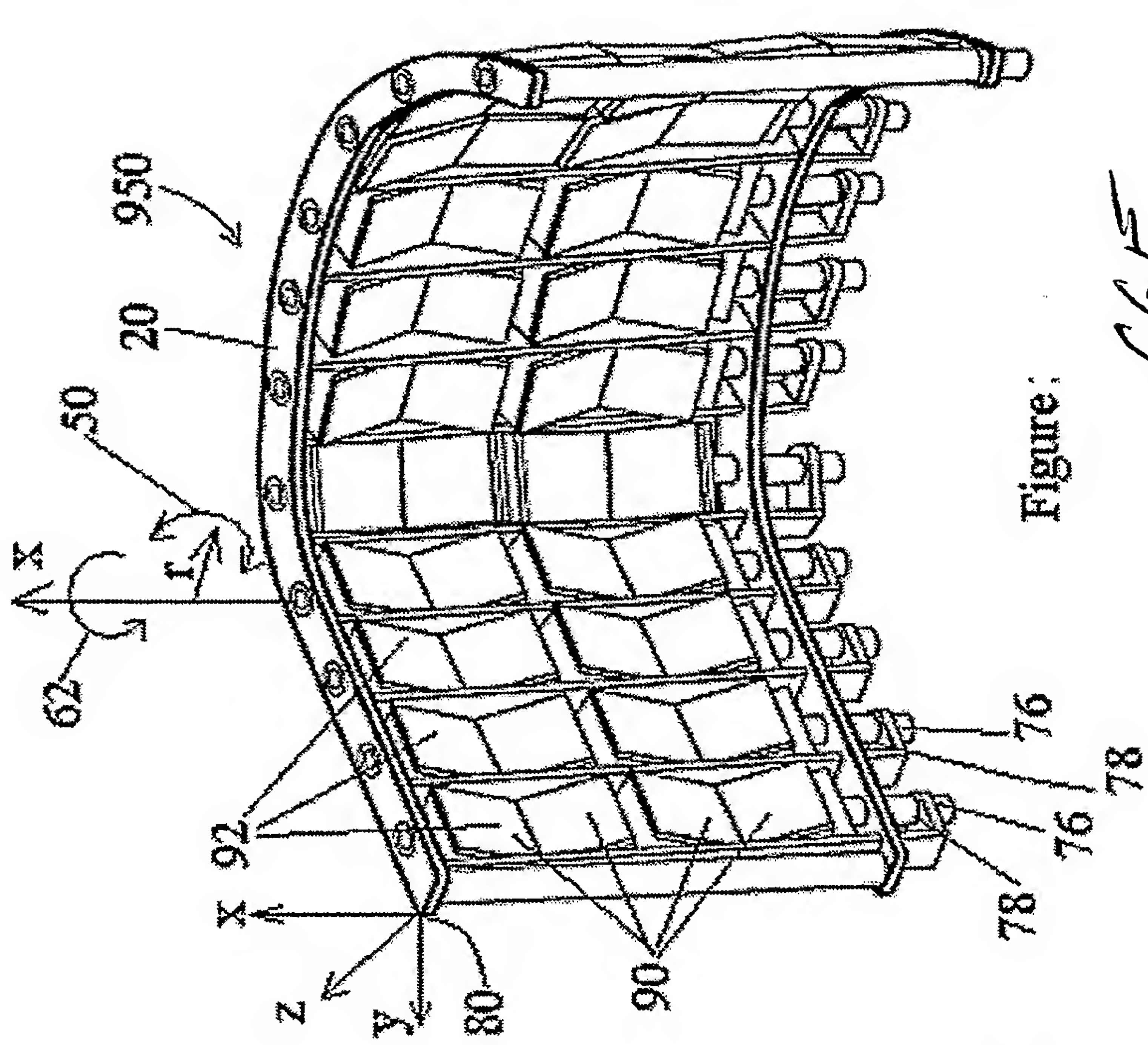


Figure: 66E

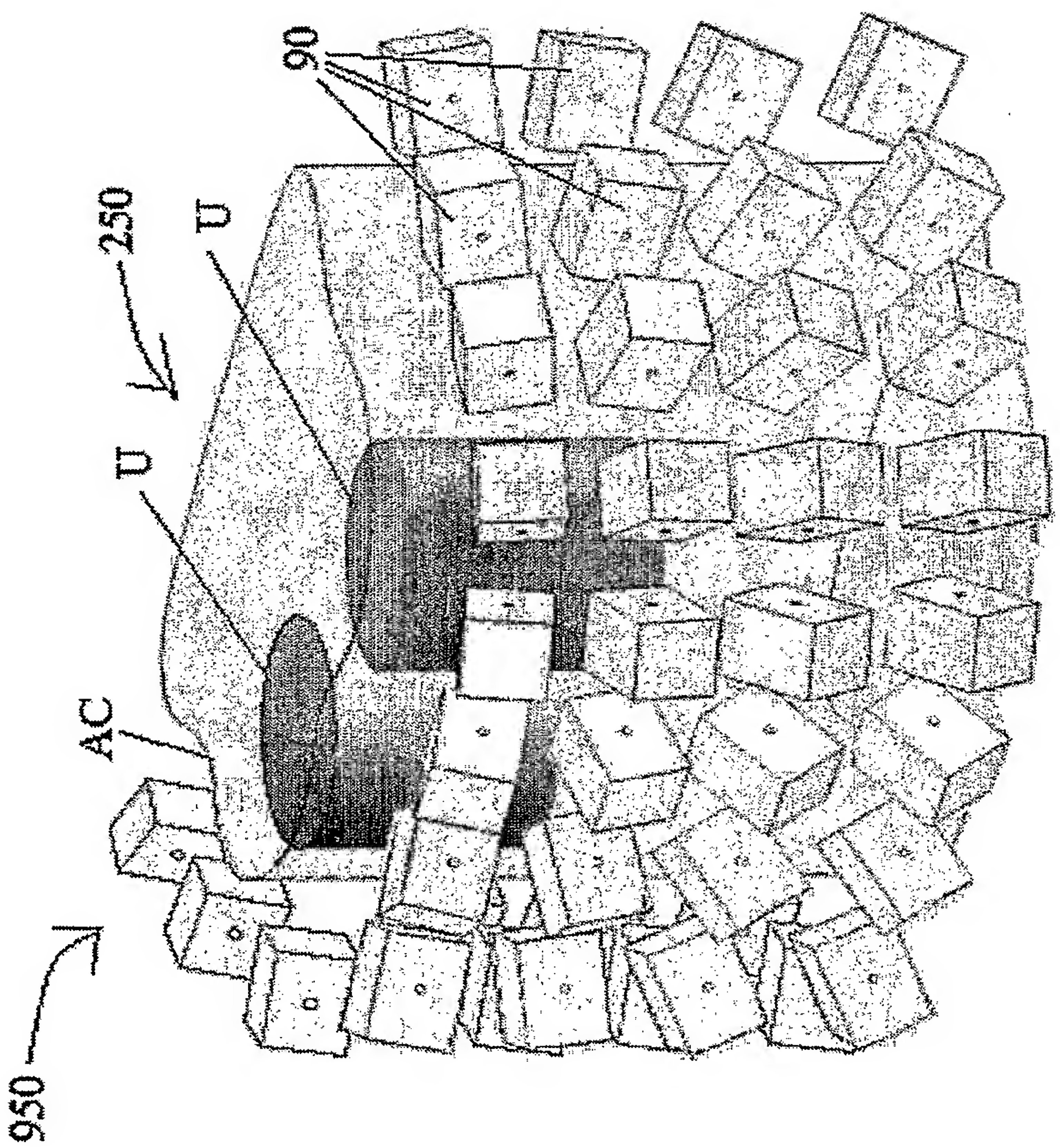


Figure 66F

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60/640,215	3 January 2005 (03.01.2005)	US
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(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

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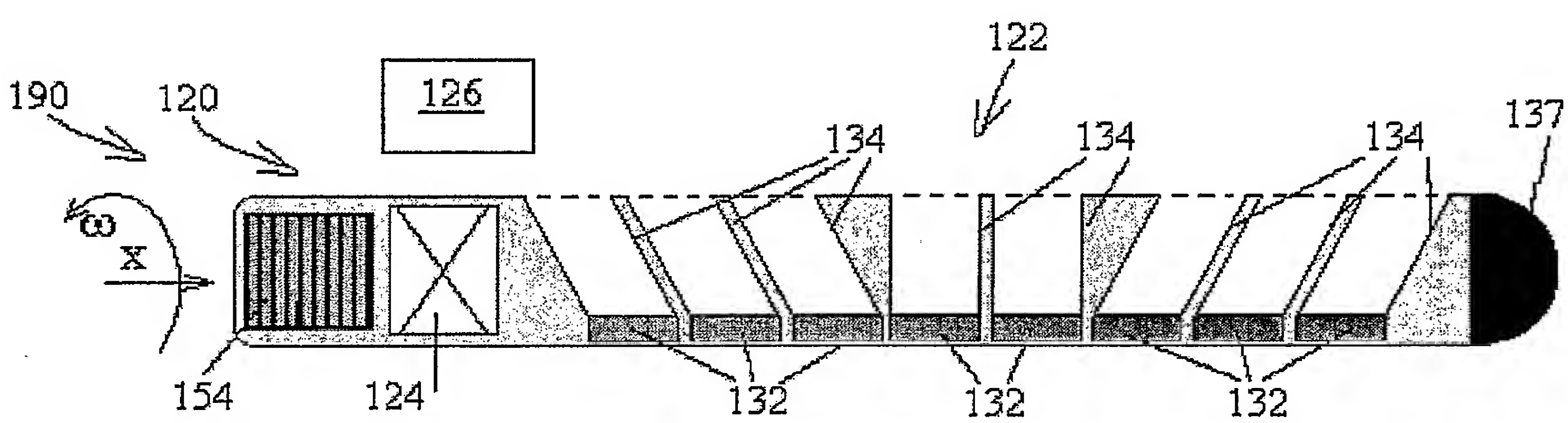
Published:
— *with international search report*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

[Continued on next page]

(54) **Title:** RADIOACTIVE-EMISSION-MEASUREMENT OPTIMIZATION TO SPECIFIC BODY STRUCTURES



(57) **Abstract:** Systems, methods, and probes are provided for functional imaging by radioactive-emission-measurements, specfic to body structures, such as the prostate, the esophagus, the cervix, the uterus, the ovaries, the heart, the breast, the brain, and the whole body, and other body structures (fig. 5c element 206). The nuclear imaging may be performed alone, or together with structural imaging, for example, by x-rays, ultrasound, or MRI. Preferably, the radioactive-emission-measuring probes include detectors, which are adapted for individual motions with respect to the probe housings, to generate views from different orientations and to change their view orientations (fig. 5c element 207). These motions are optimized with respect to functional information gained about the body structure, by identifying preferred sets of views for measurements, based on models of the body structures abd information theoretic measures (fig. 5c element 208). A second iteration, for identifying preferred sets of views for measurements of a portion of body structure, based on models of a location of a pathology that has been identified, makes it possible, in effect, to zoom in on a suspected pathology. The systems are programmed to provide these motions automatically.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IL05/00575

A. CLASSIFICATION OF SUBJECT MATTER
IPC: **G06K 9/00**(2006.01)

USPC: 382/128;128/922;250/583,586,339.06,341.2,370.08,393;600/11,436,459,2;378/1,2,4,5,11,13,16
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 382/128;128/922;250/583,586,339.06,341.2,370.08,393;600/11.436,459,2:378/1,2,4,5,11.13,16

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2003/0081716 A1 (TUMER) 01 May 2003 (01.05.2003)	1-7
A	US 2002/0103431 A1 (TOKER et al.) 01 August 2002 (01.08.2002)	1-7
A	US 6,076,009 (RAYLMAN et al.) 13 June 2000 (13.06.2000)	1-7
A	US 2002/0099295 A1 (GIL et al.) 25 July 2002 (25.07.2002)	1-7
A	US 2003/0202629 A1 (DUNHAM et al.) 30 October 2003 (30.10.2003)	1-7
X --- A	US 6,346,706 (ROGERS et al.) 12 February 2002 (12.02.2002) fig. 2 elements 28,32,34, and 60, fig. 5 elements 152-154c, col. 1lines 15-20, col. 12 line 40 to col. 13 line 25, col. 14 line 55-65, and col. 17 line 62 to col. 18 line 12.	33-39 and 41 ----------- 40

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 April 2007 (14.04.2007)	24 MAY 2007

Name and mailing address of the ISA/US	Authorized officer
Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450 Alexandria, Virginia 22313-1450 Facsimile No. (571) 273-3201	Anand Bhatnagar Telephone No. 571-272-7416

INTERNATIONAL SEARCH REPORT	International application No. PCT/IL05/00575

C. (Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,579,766 (Gray) 03 December 1996 (03.12.1996)	31,45,50,57,62,111, & 116
A	US 7,043,063 B1 (NOBLE et al.) 09 May 09 2006 (09.05.2006)	31,45,50,57,62,111 & 116
A	US 2002/0183645 A1 (NACALIEL) 05 December 2002 (05.12.2002)	31,45,50.57,62.111 & 116
A	US 2004/0101176 A1 (MENDONCA et al.) 27 May 2004 (27.05.2004)	31.45.50,57.62.111. and 116
A	US 6.549,646 B1 (YEH et al.) 15 April 2003 (15.04.2003)	31.45,50,57,62,111, and 116

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IL05/00575

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
Please See Continuation Sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of any additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☒ No protest accompanied the payment of additional search fees.

BOX III. OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I. Claims 1-7 are directed to a radioactive emission measuring probe wherein a detector in a housing detects photons and a volume of the detected photons is produced.

Group II. Claims 8-25, 27, 43, 48, 55, 60, and 114 are directed to modeling a body structure from different obtained views, scoring these views and selecting a set of views based on the scoring.

Group III. Claims 28-30, 44, 49, 56, 61, 110, and 115 are directed to modeling a body structure based on different views, scoring the views, selecting a set of views, and performing a diagnostic measurements of an in-vivo body structure.

Group IV. Claims 32, 46, 51, 58, 63, and 112 are directed to modeling a body structure from different views obtained with different probes, scoring the views, and selecting a probe design.

Group V. Claims 33-41 are directed to a detection unit in a housing that is adapted to moving in respect to the housing, a motion provider, and a controlling unit that controls the motion of the detecting unit.

Group VI. Claims 42, 47, 52, and 59 are directed to a housing with cylindrical coordinates of a longitudinal axis and a radius, and inner housing, two assemblies, two motion providers, a controller, etc.

Group VII. Claims 31, 45, 50, 57, 62, 111, and 116 are directed to modeling a body structure from different views, scoring the different views, selecting a set of different views. performing diagnostic measurements of an in-vivo body structure, identifying a suspected pathological location, modeling this suspected area, scoring views of this area, etc.

Group VIII. Claims 64-72 are directed to a bed which is adapted to motion through a 3D imaging device.

Group IX. Claims 73-78 and 119 are directed to a housing and an internal structure with detector units to obtain different views from different orientations of a patient in different positions.

Group X. Claims 79-109 are directed to a dual imaging system with a 3D imager, a housing unit with detector units and a bed for motion through the imaging device, and a controller which controls the system.

Group XI. Claim 117 is directed to a radioactive probe to measure the breasts wherein there are two plates to compress the breasts and detection units on the plates.

Group XII. Claim 118 is directed to a housing which is shaped as a cup to fit the breasts, detection units, a vacuum source, and a control unit.

Group XIII. Claim 113 is directed to a radioactive measuring probe wherein there is a frame which is designed to be worn on the head, ~~detection units, and a motion provider.~~

Group XIV. Claims 53 and 54 are directed to a extracorporeal and intracorporeal portions, a housing unit with cylindrical coordinates of a longitudinal axis, detection units, etc.

The inventions listed as Groups 1-14 do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: different techniques and technical features are required by different groups that do not correspond to a single general inventive concept.